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THE PROBLEM OF LESSIVAGE AND PODZOLIZATION

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For many years investigators have been interested in the causes of bleached A_2 horizons in various degrees of podzolization in soils. Without touching on the history of the problem, we must note that there have been and still are two opinions on the problem. The first, which was clearly stated in Glinka (5), is that during podzolization, fine mineral suspensions are removed from the upper horizons for the protection of mobile humus soils deposited in the B horizon and an acid hydrolysis of minerals occurs, but to a lesser degree. In the opinion of Glinka, who used the petrological method in his investigations, the process is powdering, or the whitish podzolic horizon related to it, is "very fine quartz which remains at the surface of small blocks after the leaching of the even finer particles of clay and ferric oxide hydrates from the surface. It thus represents the remnants of podzolization." As far as the material which has washed into the B horizon is concerned, Glinka (4), in comparing the total composition of fine clay crusts, coating structural units, with the structural units themselves, found that more total aluminum accumulates in the clay crusts than in the units themselves, but did not find free hydrates of alumina. From this it follows that very fine aluminosilicate clay particles are added into the B horizon from the upper horizons.

The other opinion of the decomposition of finely dispersed aluminosilicates in the upper horizons and the transport of their decomposition products into the B horizon, was voiced by Gedroyts (3). He compared the composition of the water extract from chernozem saturated with calcium and magnesium with chernozem saturated with hydrogen. From the latter the extract removed 0.0055% more sesquioxides, which were absent in the water extract of the brown chernozem, four times more alumina, and about two times more humus.

We consider the process of podzolization consisting of two stages.

First stage. The hydrogen ion of water releases adsorbed cations in the adsorption complex which is not protected from its penetration by simple salts, because of their insignificant quantity.

Second stage. The portion of the adsorption

complex thus desaturated of cations begins to disintegrate under the action of water: in dispersing, the humates are carried down as such, while the aluminosilicate portion of the desaturated portion of the adsorption complex is broken down by water into its components: silicon oxide, aluminum oxide and ferric oxide."

We find that the arguments of Gedroyts in favor of clay decomposition are not convincing since it is not known from which material, primary minerals, clay or plant residues, free oxides form. This question is not clarified by the experiment either, since chernozem was processed as a whole and not its clay fraction.

Duchaufour (24, 25) used the same arguments as a basis for dividing forest soils into "lessivé" (developing under broadleaf forests) and podzolic (developing primarily under coniferous forests). Duchaufour applied the word "lessivage," which in its general sense means leaching, to the processes of the movement of clay material from the upper into illuvial horizons without change in its composition (together with hydrated ferric oxides.) Duchaufour contrasted this process with podzolization, during which, as he thought, the clay in the upper horizons is decomposed and only its decomposition products move downward.

At the VI Congress of Soil Science, Aubert and Duchaufour (9) presented a classification in which soils of the lessivé group occupy a position between brown and podzolic soils in the series. The counterpart of lessivé soils in the German classification are parabrown earths. (Parabraunerde) and in the British and American classification, gray-brown podzolic and brown podzolic. Soils in the Soviet Union comparable to them are: brown podzolized and gray mountain-forest soils in the mountains and gray forest, sod-podzolic, etc. on the plains. Kundler (34), who studied samples of sod-podzolic soils of the Moscow Oblast' and gray forest soils of the Tula Oblast', came to the conclusion on the basis of micromorphological and certain chemical and thermographic investigations that these soils were analogous to lessivé soils in the vicinity of Jena.

Among the differences between the process of lessivage and podzolization mentioned in foreign literature are:

1) the presence of mobile, polarized clay in lessivé soils and its absence in podzolic soils, as determined from micromorphological investigations; 2) the similar chemical composition of clay along the profile of lessivé soils, with only a quantitative increase in clay in the B horizon, and its varying composition in the A and B horizons of podzolic soils; and 3) the similar mineralogical composition of clay along the profile of lessivé soils and its varying composition in podzolic soils.

The material collected to date necessitates the introduction of certain changes and elaborations into these characteristics.

Let us first examine the micromorphological description of three soil groups: non-lesivé brown soils, lessivé soils, and podzolic soils. There are descriptions of brown and lessivé soils of western Europe by Kubiena (33), Altemüller (18), Kundler (34), and Laruelle (36). Here we will examine the micromorphology of brown mountain-forest soils of the Caucasus, gray forest soils of the Tula Oblast' and podzolic soils of the Kostroma and Arkhangel'sk Oblasts'. The first two soils are similar to those described for Western Europe, while podzols, such as ours, do not exist there.

Brown Caucasian soil. The A₁ horizon consists of angular-granular aggregates saturated with humus. The humus is fine like mull and uniformly mixed with the mineral part. There are many pores (Fig. 1, a). There is no evidence of clay movement along the profile of these soils and the horizon in which it accumulates is designated as (B).¹ The clay material has the appearance of small scales of a felted texture (Fig. 1, b). In certain brown soils there are well-defined pseudomorphic clays along primary minerals which have not lost their initial form (Fig. 1, c).

In brown soils in the initial stage of leaching there is evidence of clay movement in the form of stria (Fig. 1, d) and films around concretions, microaggregates and primary minerals (Fig. 1, e). But this is not clay brought from above, but clay disengaged inside microaggregates. Iron became free and accumulated in diffused rings (Fig. 1, f). There is also more compact ortstein.

Gray forest soil. The A₁ horizon also consists of aggregates, but the humus is slightly coarser, there is a large amount of plant residue in various phases of decomposition (Fig. 2, a). The transitional A₂B horizon has a laminar structure in places (Fig. 2, b). In the upper part of the B₁ horizon the clay intrusions are enriched with a dark organic substance (Fig. 2, c). In the B horizon there are many yellow films of a very thin, transparent clay substance which have colloidal appearance (collod-morph), are strongly birefringent, edge the pores and segregate along fissures in the form of conchoidal intrusions,

and also coat structural units (Fig. 2, d, e). There are many iron micro-ortsteins of various forms (Fig. 2, f shows a compact micro-ortstein).

Strongly podzolic soils of the Kostroma Oblast'. The shallow litter consists of decomposed and semi-decomposed plant residues riddled by the fungi hypha (Fig. 3, a). The underlying whitish A₂ horizon is not aggregated, humus in it is dispersed or accumulates together with iron in loose and compact concretions. There are many almost undecomposed, charred plant remains (Fig. 3, b, c). A great amount of a transparent colloidal clay substance accumulates along pores and fissures in the B horizon. But in contrast to gray soils, these incrustations contain almost no dark humus and are of a light yellow color. They are shown in transmitted (Fig. 3, d) and polarized (Fig. 3, e) light. Their great uniformity can be seen.

Podzol from the Arkhangel'sk Oblast'. It is distinguished by a coarser texture. The litter consists of even coarser plant residues, among which there are accumulations of humus (Fig. 4, a). The A₂ horizon also contains dispersed humus and iron concretions (Fig. 4, b). The clay substance moving along the profile has a different appearance, because the clay moves as a whole (Fig. 4, c, d), and thus does not have the perfect orientation that finer clay has and polarizes much less under crossed nicols. There is much less of the fine colloidal clay substances here. There are abundant accumulations of iron together with humus along the profile (Fig. 4, e).

Quite a different picture is presented by sandy podzols developing on poor, well-drained parent material under conditions of a humid climate. Even though we do not have a micromorphological description of samples of such soils, because of the difficulty in collecting loose material in the field without disturbing the structure of the sample, mineral investigations by the immersion method clearly show these differences. We extracted the clay fraction (<1 μ in diameter) from the B horizon of sandy iron podzols developed on a watershed and humic-illuvial podzols from a water-logged depression in Northern Karelia. In contrast to the clay material in clay loam podzols, the oriented aggregates of which are always birefringent, sandy podzols have only isotropic films. It can be seen under the microscope that such films coat the grains of primary minerals. In iron podzol these films are represented by bright reddish-ochre iron hydroxides, and in humus-illuvial podzols these films are black-brown and consist primarily of humus. Chemical analysis reveals the presence of a great amount of aluminum in addition to a small amount of iron and silicon in the latter.

Thus, micromorphological investigations indicate that the presence of the polarized clay substance and its movement along the profile are inherent not only to lessivé soils, but also to podzolic soils and even podzols, in addition to poor sandy well-drained podzols, but the appearance and nature of the movement of the clay substance differ for soils of various

¹The designation (B) was introduced by Laatsch (44) for the horizon formed as a result of clay formation in place within the soil, but not for illuviation.

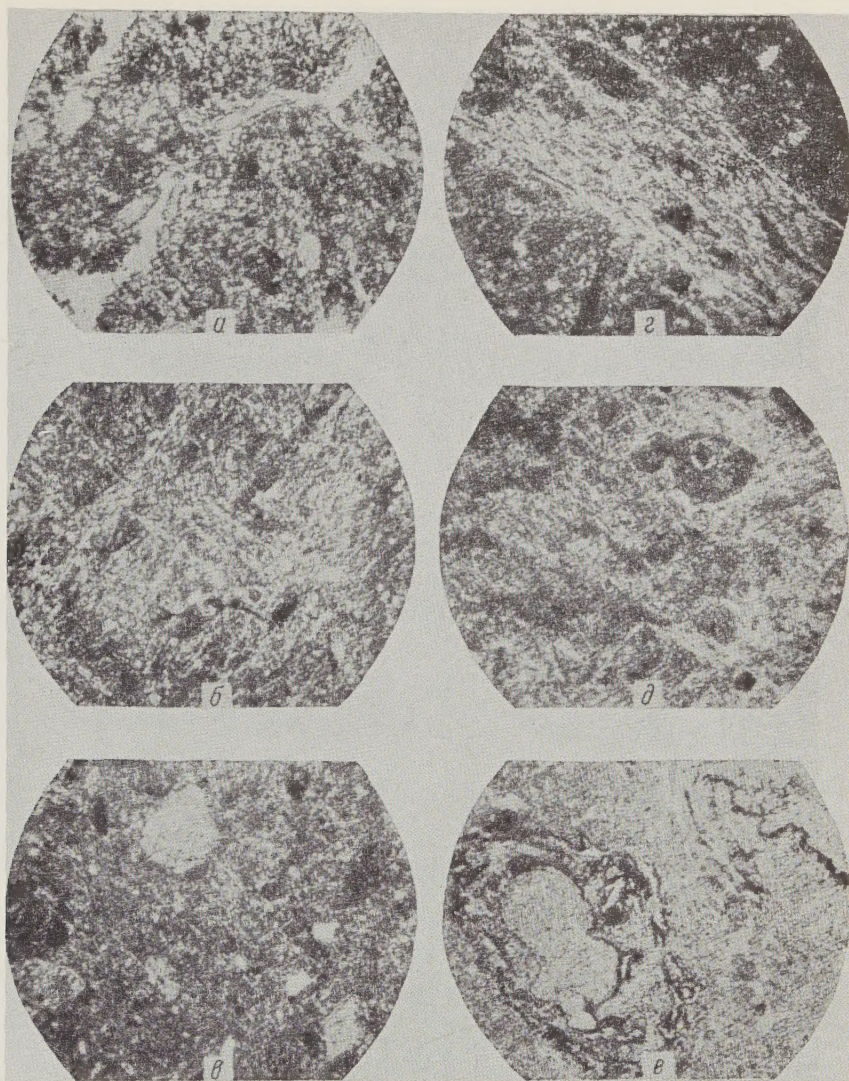


Fig. 1. - Microphotographs of brown mountain-forest soils from Caucasia. Magnification 100 x.

a - aggregates in A_1 horizon; b - oriented clay materials in a scaly felled-texture. Nicols crossed; c - pseudomorphic clay with primary mineral. Nicols crossed; d - structured oriented clay materials. Nicols crossed; e - oriented clay films around microaggregates. Nicols crossed; f - diffused rings of iron oxides.

onal groups.

Micromorphology is of great assistance in the characterization of the illuvial process in soils of various zones, its intensity, and the composition of material composing the illuvial horizon, and partly allows judgment on its sources. However, it does not give accurate information on the method of formation of the moving clay material, nor on its decomposition, or changes.

The finest colloidal part of the clay separated from the initial deposit and clay newly

formed in the A horizon can migrate into the B horizon. In addition, a synthesis of clay may occur in the B horizon from solutions which have penetrated into it and also as a result of the clay formation in place within the soil. But all these problems still require clarification.

Certain Chemical Data

One of the criterion of the decomposition of clay is the molecular ratio of $SiO_2:R_2O_3$ in the total composition of the clay fraction along the

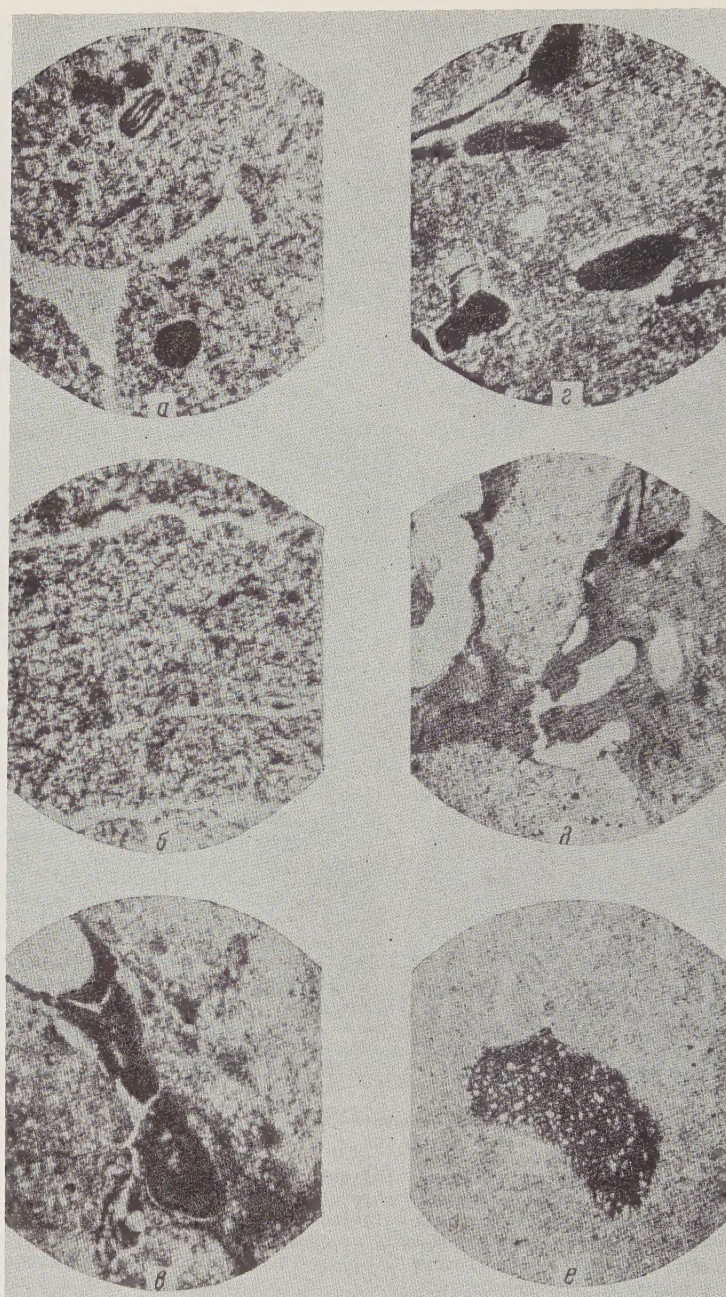


Fig. 2. - Microphotographs of gray forest soils from Tula Oblast'.
Magnification 100 x.

a - aggregates in A₁ horizon, plant residues and micro-ortsteins are visible; b - laminated structure in A₂ B horizon; c - clay film enriched with dark humus; d - colloid clay material in pores of B horizon, Nicols crossed; e - colloid clay material in cracks between structural units; f - dense micro-ortstein in B horizon.

soil profile, and Geering's coefficient (28) calculated from it, which is believed to be close to unity in brown soil, and much greater than unity in podzolic soils (the data of Geering

give 2.5-4.9 for podzols).

We calculated Geering's coefficient for a large number of soils, both from data found in



Fig. 3. - Microphotographs of strongly podzolic soils from Kostroma Oblast'.
Magnification 100 x.

a - forest litter penetrated by fungi hyphae; b - plant residue and micro-ortstein in A₂ horizon; c - non-aggregated A₂ horizon with micro-ortstein; d - conchoidal intrusion of colloidal clay materials in the pore of B horizon; e - the same, Nicols crossed.

literature and our own material.² The calculations showed that various soil groups, as brown, lessivé and even highly podzolic soils and certain podzols, may have similar molecular ratios of $\text{SiO}_2:\text{R}_2\text{O}_3$ within

was calculated by dividing the molecular ratio of R_2O_3 in the total chemical composition of clay A₂ horizon by the same ratio in the B horizon.

the limits of each profile, so that in such a case Geering's coefficient is the same for various soils (~1). Only in sandy soils or in podzols developed on coarse deposits, do these ratios differ in the A and B horizons so that Geering's coefficient becomes much higher (up to 4-3). Apparently this criterion has not proved itself and can only be used for differentiating between the outer groups of this soil series. This makes the highly elaborate and high values of Geering's coefficient for

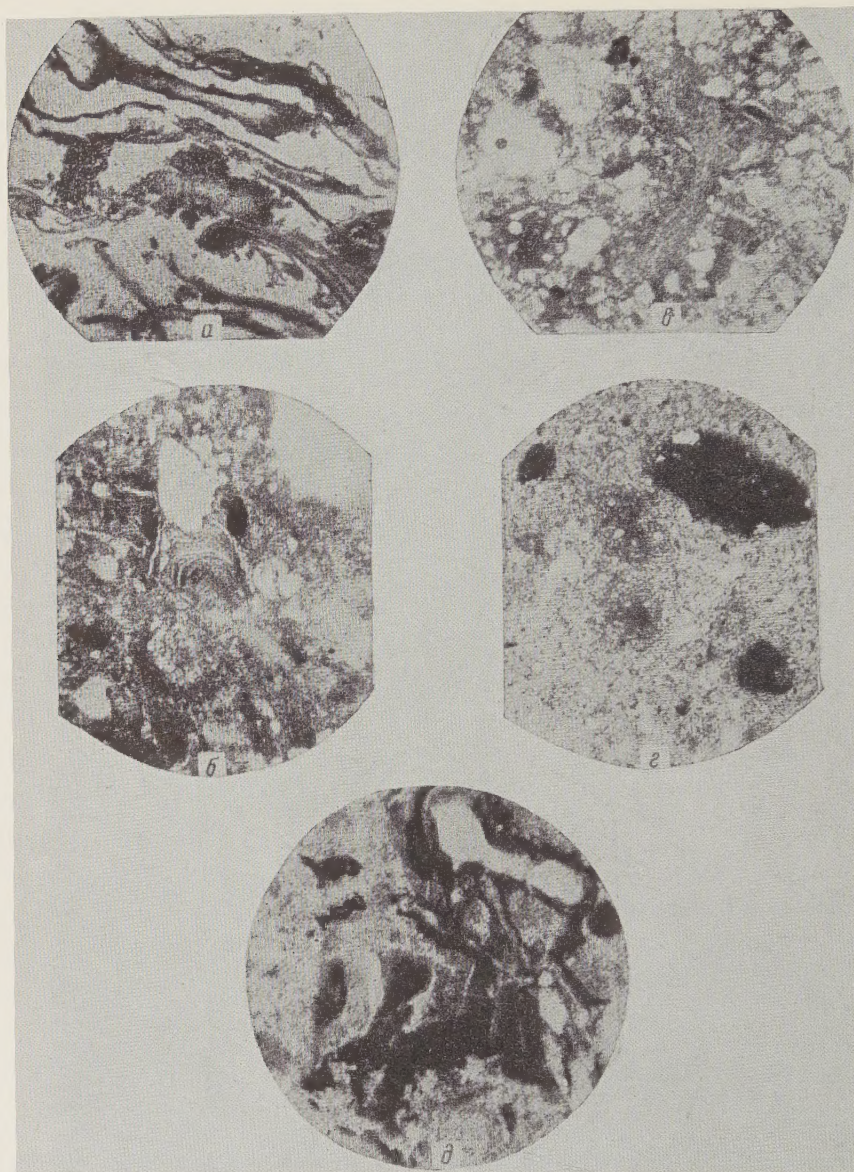


Fig. 4. - Microphotographs of podzol from Archangel'sk Oblast! Magnification 100 x.

a - forest litter with slight decomposition of plant residues; b - non-aggregated A₂ horizon with micro-ortstein; c - migrated clay in the entire pores of B horizon; d - conchoidal intrusions of colloidal clay materials in pores of B horizon; e - accumulation of iron oxides and humus in B horizon.

soils of the lessivé group in the classification of Aubert and Duchaufour the more surprising.

The least clarified of the problems is that of clay decomposition during podzolization. Soil scientists often proceed from the assumption that the smallest particles are most easily decomposed. Existing mineralogical and certain chemical data indicate something else. Thus, Jackson (31, 32), in generalizing a wealth of experimental data on the mineralogical composition of the fine fractions of soil and deposits,

came to the conclusion that clay minerals belong to the most stable minerals. He noted that the rate of weathering of primary minerals increases with decreasing particle size, while the degree of dispersion of clay minerals has little effect on the decomposition rate.

In studying the mineralogical composition of podzol, Van der Marel (48) found that among finely dispersed fractions only quartz and clay minerals are very resistant to weathering.

Thorp (46) conducted experiments on artificial podzolization by filtering solutions of certain organic acids (0.1 N oxalic acid, 2.5% lactic acid, etc.) and water extracts from the leaves of various woody plants through a column filled with the material found in the B horizon of gray-brown soil. After leaching, the profile had a podzolic appearance. The filtrate obtained was examined by the X-ray method and chemically analyzed. It proved that the clay substance had moved from the upper into the lower horizons beyond the limits of the column without having suffered a change in mineralogical and chemical composition under the effect of the reagents used.

Chemical investigations on the stability of clay minerals under the effect of 0.1 N hydrochloric acid and 0.5 N acetic acid, made by Zalmanzon and Shishova (8), showed that montmorillonite, halloysite, kaolinite and hydromica dissolve very little, from 2.5% - 0.36%.

There is not enough reason to think that the presence of free hydroxides in the B horizon in podzolic soils is an indication of the decomposition of a particular clay, since these hydroxides may form also as a result of the decomposition of primary minerals and the mineralization of plant remains. The literature gives experimental data which show that the weathering of primary minerals occurs in all soils, along the entire profile, but most intensively in the upper horizons of podzolic soils. The source of free oxides is primarily unstable minerals. For instance, iron hydroxide forms from pyroxenes, hornblende, biotite, etc. There are indications from Cady (22) that as podzolization proceeds these minerals are decomposed more and more intensively. A little iron also exists in feldspar, from which it is easily extracted. This is also substantiated by our experiments on the leaching of a column of fresh microcline with water extract from decomposing plant residues. The extracted iron forms brown accumulations among the grains of microcline. The extraction of iron forcibly leads to the loosening of the lattice and it becomes easier to extract also silicon, alumina, and other oxides. The presence of free oxides is not only inherent to soils of the podzolic group. Lamberts and Livens (35) found similar amounts of free iron in a series of soils starting from brown carbonate soils to lessivé and podzolic soils. Iron oxides are set free in brown carbonate soils even before the complete removal of carbonates, i. e., not under the influence of the podzolization process, but during weathering within the soil.

The problem of the movement and decomposition of clay was also discussed by Fridland (13, 14) in articles which were the first response to our need for the distinction of lessivé soils by European scientists. To designate the simple mechanical movement of clay in soils, Fridland introduces a new term "illimerization" instead of "lessivage." To verify the assumption of the possibility of a movement of the clay fraction along the profile without its differentiation, he derived the formula

$$S_x = S_0 \pm (b - a_x) \frac{S_1}{100},$$

in which S_x is the percentage of the oxide studied in the soil horizon x ; S_0 is the percentage of the same oxide in the material; S_1 , the percentage of the same oxide in the clay fraction; b , the percentage of clay in the material; a_x , the percentage of clay in the horizon x . The formula is valid only in the case of soils having the same clay composition in all horizons and is derived on the basis of the following assumptions: 1) that the parent material is homogeneous; 2) weathering, including clay formation, takes place at the same rate in all horizons; and 3) the differentiation in texture and total composition results only from the movement of unchanging clay along the profile.

We think that this formula does not fulfill its purpose. First of all because the formula expresses only the direct dependence of the content of an oxide in a given horizon (S_x) on the amount of clay in it (a_x), since all values, except these two, are assumed to be constant — but it does not show where the clay comes from. With the same result we may assume that clay was added into the B horizon by the lateral influx of ground water. In the second place, the second assumption (that of the equal rate of weathering and clay formation along the profile) does not correspond to natural conditions, while the first requires special investigations to prove the homogeneity of the parent material, which was not done.

The author believes that if there is no disagreement between values calculated by this formula and those obtained analytically, this would substantiate the correctness of the assumptions made. But it is quite clear that as long as the assumptions do not correspond to actual natural conditions, as we have shown them, there must be deviations. And there were deviations, but of various degrees for various oxides. The deviations were small only for silicon, which is natural, since they were calculated in percent of the total content of the oxide and will be the smaller, the larger is the amount of this oxide in the soil. Thus, with an SiO_2 content of 67%-80%, a discrepancy of one unit between the calculated values and those obtained analytically gave a deviation of about 1%; for oxides contained in smaller amounts, the same discrepancy of one unit gave a greater deviation: up to 8% for aluminum, up to 38% for iron, and even much more for magnesium, calcium, etc. It remains unclear what the limits of the deviations should be in order to be able to speak of the process of "illimerization" as the main process in the investigation of soils. Fridland explains these deviations by the most varied natural phenomena: gleyization, the stability of weathering minerals, pH, the action of plants, etc., which are not related to "illimerization" any more. That the formula does not give a satisfactory solution is evident from the concluding part of the article in which it is stated that in order to determine whether clay moves in a decomposed or not decomposed state, all methods existing in soil science must be used. As long as a process of this type has not been studied enough, it is not expedient to use the term "illimerization," the more so since this term, as used by Fridland, has two meanings: in the first article (15) the word "illimerization" is derived from the Latin *illimare*, or to add clay,

and in the second (16) it is used to mean the removal of clay.

For the study of the process of clay movement along the soil profile, a method of calculation was proposed earlier by Marshall and Haseman (37), based on a mineralogical basis, allowing the determination of the homogeneity of the parent material, which is a necessary assumption for such calculations. Without going into the details of the method, let us only mention that the addition or loss of clay in a given soil horizon is calculated in relation to the content of stable minerals (in particular zirconium) in the profile. One may calculate the magnitude of the change in weight of a present soil as compared to that of the parent material from which it had developed, provided the composition of particles larger than 0.05 mm in diameter is homogeneous and stable minerals are evenly distributed by size of fractions, and taking into account specific density. The difference in weight gives the amount of clay formed. However, Marshall rightly warns that such calculations require a thorough study of easily changing minerals, first of all feldspar, which serve as one of the sources of clay, and also a verification by chemical analysis.

Mineralogical Characteristics

In order to determine whether the mineralogical composition of clays varies in the soil group studied, we made a thorough study of the literature of various countries. In spite of the fact that the number of analyses made by various methods (X-ray, thermal, etc.) is generally great, they very unevenly characterize the various soil groups and also individual horizons. Only in single works is there a more or less full characterization of clay minerals along the entire profile, based on the use of complex methods, including chemical methods. There is no unity in the selection of the size of clay fractions; the fractions most generally used are of diameters $<2\mu$, or $<1\mu$, and more rarely $<0.5\mu$, $<0.3\mu$, $<0.2\mu$ and $<0.08\mu$. In generalizing the material it is very difficult to compare these data, because fractions of various sizes are not fully identical in the composition of minerals: coarser ones contain a noticeable amount of primary minerals in the form of impurities (1, 2), while smaller fractions contain primarily minerals of the montmorillonite group (43) and amorphous substances.

We found least information in the literature on the clay minerals of not podzolized brown soils. Geering has X-ray data on these soils, obtained in 1936. He found minerals of the montmorillonite-nontronite group and hydromica containing iron in the two horizons studied, A and C. Martin (39) gives thermal curves and certain data from X-ray analysis for brown forest soil in the State of New York, which show that the main clay mineral is illite with a small addition of chlorite and quartz. McCaleb (40) found illite to predominate among the minerals in brown forest soils of New York, with small additions of vermiculite and montmorillonite; there were also indications of an insignificant amount of kaolinite. Data of Rubilin³ (11) (Footnote No. 3 in next column).

refer to weakly podzolized brown forest soils, investigated by the X-ray, thermal, and optical methods. The author believes that minerals of the montmorillonite group predominate in the clay fractions of these soils, their amount increasing with depth beginning from the A₂B horizon. In the upper part there was an admixture of amorphous substances and a small amount of hydromica.

There is much more information on soils of the lessivé group in the literature. The soils investigated most are brown podzolic and gray-brown podzolic soils of the United States.

McCaleb gives diffraction curves and thermograms of the $2-0.2\mu$ and $<0.2\mu$ particle diameters of gray-brown forests soils and brown podzolic soils of New York. The predominant clay mineral in these soils was illite. However, the first line near 10 kX is broader on the X-ray photograph of the A horizon than is natural for illite and indicates that illite is present here in a modified form.

Articles of Martin (39) and Martin and Russell (38) given results of X-ray, and thermal investigations, and investigations of ethylene-glycol saturation, potassium content, and adsorption capacity of nine profiles of gray-brown and brown podzolic soils. The particles of $<1\mu$ diameter were investigated in five profiles and the $2-1\mu$, $1-0.5\mu$, $0.5-0.2\mu$ and $<0.2\mu$ diameter fractions in four profiles. The author concludes that illite comprises 50%-85% of the clay minerals of these soils. Many samples, mostly the upper horizons, contained chlorite. Iron and aluminum hydroxide minerals were found in the fine fractions.

Using the X-ray method, Thorp (47) found illite, montmorillonite and vermiculite in various quantitative ratios and a little kaolinite in the $<2\mu$ diameter particles of gray-brown podzolic soils of Miami (Indiana), whereby in the A horizon montmorillonite was poorly crystallized.

Ehrlich (26) and others investigated the particles of $2-0.2\mu$, $0.2-0.1\mu$ and $<0.1\mu$ diameter fractions of gray wooded and brown podzolic soils of Manitoba (Canada) by the X-ray and thermal methods. In both soils, the montmorillonite, illite, and interlayer minerals with admixtures of other minerals (chlorite, vermiculite, hydromica, kaolinite, feldspar, quartz, hematite, etc.) predominate. In Canada, on the other hand, Warder and Dion (50) found by X-ray and thermal analyses that the $<1\mu$ diameter particles of gray forest soils of Saskatchewan consists primarily of minerals of the interlayer type (layers of the type of illite and beidellite).

Kundler (34) analyzed the $<2\mu$ diameter particles of lessivé soil from near Jena (Parabraunerde). He believes that the clay portion of the soils is represented by a mineral inter-

³The X-ray and thermal analyses in the articles of G.V. Rubilin, I.V. Zaboyeva, Ye.N. Rudneva, N.N. Parfenova, and Ye.A. Yarilova were made in the soil mineralogy laboratory of the Soil Institute of the Academy of Sciences of the USSR.

mediate between illite and montmorillonite, most probably of a mixed-layer structure.

Rudneva (12) found that minerals of the type of beidellitic hydromica and hydromica are contained in greatest amounts in light-brown podzolized soils of the Carpathian foothills.

Data on sod-podzolic soils of the Moscow and Amur Oblasts are given by Gorbunov (6). Thermal and X-ray analyses of the $<1\mu$ diameter particles showed the predominance along the entire profile of amorphous substances and minerals of the montmorillonite group (beidellite) with admixtures of quartz and hydromica.

Let us turn to the clay minerals of soils of the podzolic group. There are no data in the foreign literature on podzols proper (corresponding to podzols of the northern part of our taiga zone). There is an article by Feustel and others (27) on soils of the arctic regions of North America, published in 1939. Samples of 37 soils were collected in the northern part of the Hudson Bay and on Baffin Island, Latty Harbor, etc. On the basis of the molecular ratios of $\text{SiO}_2:\text{R}_2\text{O}_3$ (1.9-2.9) and $\text{SiO}_4:\text{Al}_2\text{O}_3$, X-ray and thermal data, as well as the amount of potassium (2%-4.7%), the authors decided that the clay mineral predominating in these soils is hydromica, with a possibility that it may be illite mixed with a small amount of kaolinite.

Zaboyeva (7) gives data of X-ray and thermal analyses of the $<1\mu$ diameter particles of three horizons of gleyey-strongly podzolized soils of the Komi ASSR. The distribution of clay minerals along the profile is rather uniform. Among these, amorphous substances (up to 50%) and minerals of the montmorillonite group (up to 40%), such as beidellite and ferribeidellite, which are now considered as mixed-layered minerals, predominate. The amount of hydromica is about 10%, that of mica, 10%-15%, and that of quartz, 2%-5%.

The work of Canadian investigators refers mostly to soils close to sod-podzolic, or gray forest soils. In the above-mentioned article of Ehrich and others the results are given of investigations of podzolic soils of Manitoba. X-ray and thermal analyses of the 2-0.2, 0.2-0.1 and $<1\mu$ diameter-particles revealed the presence of mixed-layered minerals, montmorillonite, illite, chlorite, hydromica, and admixtures of hematite, kaolinite, etc.

There are descriptions of podzols developed on sandy parent material in more southern regions of the USA and Europe. Tedrow (45) investigated three podzols in Eastern Pennsylvania. The X-ray analysis of $<2\mu$ diameter particles showed that mixed-layered minerals predominate in all horizons; there is 10%-25% quartz, a small amount of illite, and traces of kaolinite in the A_2 and B horizons with additions of vermiculite, chlorite, and a lesser amount of quartz (about 5%) in the C horizon.

Van der Marel (48) investigated the sandy podzol of the Low Countries, which contained about 2% of the $<2\mu$ diameter particles, and found in it illite and kaolinite, derived, in his opinion, from schist from which the local soils developed. Among newly formed minerals in

the soils he mentions boehmite.

Duchaufour's data (24) stand out among these materials. Without giving the results of his experiments, he points out that in the $<0.5\mu$ diameter particles of the podzols investigated by him he found quartz in the A_2 horizon and kaolinite and free hydroxides in the B horizon. We never found such data any place else.

We studied the $<0.2\mu$ diameter particles from illuvial horizons and, in certain cases, the entire profile of certain soils of the groups examined, such as podzolic, sod-podzolic and gray forest soils (16, 17). The colloids were subjected to microphotographical, chemical, optical, X-ray, thermal, and electron-microscope examination. Structural formulas were derived for them (17). We found that in the composition of the colloids⁴ of these soils similar highly disperse three-layer dioctahedral clay minerals in which Si^{4+} was replaced by Al^{3+} in the tetrahedra predominated. The properties of these minerals point to the intermediate nature between minerals of the beidellite-montmorillonite series, and illite. They possess an incomplete crystal lattice and their non-swelling (predominant) and swelling strata alternate irregularly.

Such minerals were often called (also by us) soil beidellite, and ferribeidellite, which was partly founded, since minerals of the montmorillonite group, in the lattice of which silicon is replaced by aluminum in the tetrahedral layer, are called beidellite. However, the presence of potassium in soil beidellite had not been taken into account. That this has nothing to do with the presence of an admixture of illite is shown by the absence of a clear 10 kX line in X-ray photographs. Unfortunately little attention had been paid to the mention of Ross and Hendricks (42) that "in nearing the beidellite end of the montmorillonite-beidellite series there is a pronounced tendency for the formation of minerals with lattices of a mixed type; containing potassium. More precisely, the more the number of exchangeable ions between layers (primarily K^{+}) increases, the more Si^{4+} is replaced by Al^{3+} in the tetrahedral coordination. This shows that a gradual transition between minerals of the beidellite type and micaceous minerals with a moderate content of potassium may take place."

The accumulated experimental material indicates that the mineral which strictly corresponds to ideal beidellite, the octahedral layer of which is occupied by aluminum and a small part of Si^{4+} is replaced by Al^{3+} (~12%) in the tetrahedra, is found in nature in exceptional cases. Mixed-layered minerals, which, as seen from the foregoing quotation, represent a branch of the end of the montmorillonite-beidellite series tending in the direction of micaceous minerals, are much more widely distributed.

We can compare our data with those found

⁴And also colloids separated from soils of other groups, such as chernozem, solonchets, chestnut, etc., which we do not include in the present article.

in foreign literature only in rare cases because the articles usually mention only the presence of given clay minerals and do not give the initial data. But when they are given, we become convinced of the great similarity between clay substances in the composition of various soils of the boreal zone. Thus, for instance, our X-ray data for particles $<0.2\mu$ in diameter of a number of soils proved similar to those obtained by McCaleb (40) for the same fraction of gray-brown podzolized soils of the U.S., i.e. of another continent. Also, structural formulas calculated by Warder and Dion for Canadian soils almost fully agree with our formulas for our soils. Thermograms given by Kundler (34) for lessive soils of Germany and our thermograms for our gray forest and sod-podzolic soils proved to be almost identical.

Investigations of the last ten years reveal more and more the presence of mixed-layered clay minerals in the composition of soils, among which such minerals are primarily mentioned, the lattice of which includes montmorillonite and illite layers. Jackson and others (31) in an earlier work called such minerals "intermediate mica" and later "intermediate micaceous-montmorillonite mineral" (32); we called them polynite (16). They are characterized first by a broad line on a 12-13 kX X-ray photograph, which can be explained by the disorderly layering of structural layers with a spacing of 10 (illite) and 14 (montmorillonite) kX.

The literature and our own investigations lead to the conclusion that mixed-layered clay minerals, distinguished by high stability or an intimate mixture of illite with minerals of the montmorillonite group, predominate in all the soils of the wide boreal zone examined, such as brown soils, soils of the lessive group (of foreign authors), and our gray forest, sod-podzolic, strongly podzolized soils, and podzols. An admixture of kaolinite is often found in strongly podzolized, and podzolic soils. Sandy podzols on poor, well-drained deposits contain only amorphous minerals—oxides and hydroxides.

Formation of Clay

The problem of the decomposition and movement of the clay substance in soils cannot be examined without examining the problem of the origin of clay minerals and their transformations. However, these processes are complicated and have been studied very little. The prevailing opinion is that the formation of clay is most intense in soils developed on massive-crystalline material which has large amounts of yet unmodified primary minerals that can change into clay minerals. It is believed that there is no such rich source for the formation of clay in soils developed on various types of sediments, because only the most stable primary minerals are preserved in them, and, in the opinion of a number of authors (28, 45, 49 and others), clays are derived here almost exclusively from the deposit proper.

There are observations by Thorp (47), Hutcheson (30), and certain others on the problem of the differential movement and modifica-

tion of clay minerals in soils. Thorp indicates that the quantitative ratios between clay minerals vary along the profile of the gray-brown podzolic soils of Miami (Indiana). Thus illite predominates in the deposit and in the lower part of the B horizon. Montmorillonite accumulates in the B_2 , B_3 and C_1 horizons there is very little of it in the A_2 horizon and a little more in the A_1 horizon, but its structure here is less organized. Vermiculite is found in all horizons but there is more of it in the upper part of the profile. There is very little kaolinite along the entire profile, but it accumulates to a certain degree in the podzolic horizon. Thorp explains it first by the transition from one mineral to another and, secondly, by the preferential movement in the complex of montmorillonite among the minerals, together with organic compounds. Such observations show, in particular, that the problem of the mechanical movement of undifferentiated clay cannot be solved that simply.

Speaking of the mechanics of clay formation in soils, the following ways may be distinguished.

1. Gradual modification of primary minerals. It may take place: a) without a substantial change in the structure of the crystal lattice, for instance, the transition from mica to illite. Apparently a further transformation of illite may take place through the stage of mixed-layered minerals into minerals of the montmorillonite group (42, 31). This series of transitions is characterized by the removal of potassium, an increase in hydration and the appearance, associated with it, of swelling layers in the lattice; and b) the reconstruction of the crystal lattice of the primary mineral. An example of this is the transition of feldspar of a skeletal structure into clay minerals with a layered lattice. Apparently a gradual transformation of the mineral, starting from its upper layers, and the pseudomorphosis of clay along the primary mineral take place here (23). After complete replacement, the crystal form of the primary mineral is clearly noticeable in the clay mineral derived from it (as it occurs in the red earths of Batumi, for instance), both microscopically and macroscopically. Marshall showed that during the soil process, the weight of the soil increases as a result of the formation of the clay substance. Proceeding from it, he believes that the accepted idea of the formation of kaolinite from feldspar during the removal of silicon and cations by ground water is wrong. In this case no increment in the weight of soil can occur. Marshall believes that re-synthesis of clays of the beidellite-montmorillonite group from the decomposition products of feldspar, accompanied by the introduction of silicon into the composition of the crystal lattice and that of cations into the adsorption complex, is more likely.

- 2) Synthesis of clay minerals. There are very little direct data to testify for the possibility of the synthesis of clay minerals from soil solutions. The most accurate information in this respect is obtained from the study of soils developed on massive-crystalline materials, which contain no clay substance. The investigations of Polyanov (9) in the Il'men' Reservation are well known. He found that as a result of the simultaneous humification and mineralization of plant residues, clay minerals of the montmorillonite and illite group synthesize in primary

ne earths. The observations of Yarilova (15) showed that a transparent, colloidal, birefringent clay substance deposits in the form of incrustations on the walls of pores in andesite-sasalt. It undoubtedly forms here from solutions, since there is no previous clay here.

The problem of the synthesis of clay in soils developed on deposits is much more difficult to solve, because we do not know yet how to distinguish newly-formed clays from those inherited from the deposits themselves and judge of clay formation primarily from indirect evidence. That clay formation takes place in such soils is evidenced by the calculations of Marshall (29, 31). Barshad (20), who also made such calculations, arranges soils according to the intensity of clay formation in the following series: podzols < gray-brown podzolic soils < brown earths < steppe soils < red earths and yellow earths < laterites.

Lately discussions of the role of vegetation in clay formation have begun to appear in the foreign literature. Thus, Barshad notes that herbaceous vegetation is more effective in this respect than woody vegetation. The literature on the composition of ash in plants explains this fact by the higher amount of ash elements introduced into the soil during the mineralization of the roots of herbs than during that of the roots of woody plants (10-30 times more), as we understand it. In addition, the roots are richer than the tops in sesquioxides and, sometimes, in silicon, i.e., elements which are basically the building blocks of the lattice of clay minerals.

Buol and Hole (21) speak definitively of the participation of plant residues in the formation of clay in a recently published article. They studied incrustations of a polarizing clay substance in the illuvial horizon of gray-brown podzolic soils of Wisconsin and came to the following conclusions on the possible origin of such films.

1) The films may synthesize from elements which had moved down the profile with water in the form of organo-mineral compounds. 2) They possibly represent deposits of clay suspensions filtering through the soil along fissures and pores. 3) Clay films may form in place from elements liberated both during the decomposition of roots and during the weathering of minerals.

Much work is needed to clarify the problem of clay formation, but ways of making such investigations are much more clear now. The most important problem is that of determining the conditions of clay synthesis in soils and the role of organic substances in this process. As the degree of podzolization of soils increases and the aggressive role of fulvic acids increases, the more the synthesis of clay minerals is hampered, as a result of the increased ability of elements to move under these conditions, as is shown by Polyakov (10).

There is no doubt about the necessity of combining the work of soil scientists-mineralogists, soil scientists studying organic matter, and microbiologists, in order to solve these problems. This work must be done by using

complex modern methods on one and the same object according to a program worked out jointly.

Conclusions

1. Soils cannot be classified according to the movement of non-decomposed or decomposed clay and the processes of lessivage and podzolization cannot be contrasted (as Duchaufour does), because of the following considerations.

a) The movement of clay particles can be easily traced by micromorphology. It manifests itself in polarizing incrustations in all soils to which the illuviation process is inherent, which have their own peculiarities in soils of various zones. The only exception are sandy podzols developed on poor, well-drained parent materials, which do not contain polarizing clay incrustations, but only amorphous films.

b) The problem of the clay decomposition and the movement of the decomposition products along the profile of podzolic soils has not been studied enough experimentally. The decomposition of clay is determined primarily from the presence of free oxides in soils, however their appearance may be due to the decomposition of clay and primary minerals and the mineralization of plant residues; the individual quantitative determination of such a decomposition under natural conditions is not possible yet. There is a lot of material which testifies to the comparatively high stability of clay minerals in soils. Indications of the differentiation in the movement of clay minerals and the possibility of a transition of one to the other should also be taken into account. This is why it is not expedient to use the term "illimerization," which expresses the transport of undifferentiated clay.

c) The composition of clay minerals is very similar in all soils of the boreal zone: the predominant minerals are those with an imperfect three-layered crystal lattice, most probably mixed-layered minerals with a disorganized alternation of non-swelling (illite), and swelling (nontronite-beidellite series) layers, or intimate mixtures of illite with minerals of the montmorillonite group. Only poor sandy and well-drained podzols contain primarily amorphous minerals of sesquioxides.

d) The study of the movement and decomposition of clay should not be separated from the problems of clay formation, which takes place in all soils, except apparently in sandy podzols, in spite of the fact that there are sources of clay formation (feldspar, mica, etc., as well as vegetation) in the latter. This may be related to the fact that the synthesis of clay is hampered here. But this problem needs elaboration as far as the varying ability of elements to migrate under various natural conditions is concerned.

2. The classification of soils by Soviet scientists is established on a broad genetic basis, which takes into consideration the process of soil formation in all its various aspects; it takes into account, in particular, the increasing intensity of leaching and all associated characteristics in the examined series: gray forest soils — sod-podzolic soils — podzolic soils — podzols, and under mountain conditions brown

soils — brown podzolized soils — gray mountain-forest soils, etc. The concept of podzol formation is wide and includes among other characteristics both the simultaneous processes of clay transport and the decomposition of minerals, including clay minerals; the new formation of the latter is not excluded.

Complex investigations, including mineralogical investigations, are required for a more detailed classification.

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PROBLEM OF THE WATER BALANCE AND MOISTURE CYCLE UNDER CONDITIONS IN THE SOUTHEAST

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The importance of soil moisture is especially great in the arid belt of our country. Here its deficiency very often paralyzes the influence on yield of other favorably combined elements of the fertility of chernozem.

Izmail'skiy (9) was a pioneer in the study of the water regime of chernozem. At the end of the last century, permanent investigations of the water regime of soils were made by Vysotskiy in the Veliko-Anadol Forestry (6). Almost at the same time similar investigations in experimental agronomy were made by Rotmistrov (24). V. R. Vil'yams rightly said that these investigations had a great influence on the solution of problems of the nature and development of steppes and methods of drought and crop failure control.

The study of the water regime of soil by experimental institutions of the Southeast were associated with the solution of individual problems of arid field management and were often conducted as auxiliary observations. These investigations were concerned with: the amount of atmospheric precipitation which could penetrate into the soil and their utilization depending on the state of cultivation of the surface (20, 22, 25, 28); soil moisture contents derived from autumn and winter precipitation in the root zone of the soil in spring, depending on the method of soil tillage and snow retention practices (11, 12, 15, 16, 23); the moisture requirements of various plants in the field (transpiration coefficients) (10, 14, 26).

All these investigations had a certain influence on the development of methods of dry land management. The next step was the study of the principal elements of the water balance and water cycle, combined in the system of the water regime of soil under crop rotation. The investigations were conducted by the author from 1937-1953 in the two crop rotation fields on southern and ordinary chernozem of the experimental field and seed stock farm of the Southeastern Agricultural Institute in Saratov. A short description of the soil in the crop rotation field and methods of investigation are given in articles published by the author.¹ Winter precipitation comprises one third of the

total precipitation. However, its role is very great in the water balance.

The principal role in the water available to almost all crops grown in the Southeast is played by the moisture content in soil at the spring season. The decisive role in the amount of this water is played by winter precipitation. Summarized long-period data on the water contents in the upper 150 cm of soil in the crop rotation fields are given in Table 1.

The importance of winter precipitation in the moisture contents in the root zone during the spring season varies from field to field. For the most part it is determined by the preceding history of the field and the nature of the autumn soil moisture, soil structure, and snow cover depth. Winter precipitation plays the greatest role in sod land, in tilled soil and row crop after winter crops, and the least role in winter crops after black fallow. The share of winter precipitation in the soil moisture during the spring season of fields plowed in the late fall, of after sod land and also in soil under perennial grasses was 70% in nine fields under crop rotation, and was the major source of water supply to agricultural plants during their growth. This is clearly evidenced by long-period data on water losses from the water storage of the root zone during the growing season (Table 2).

As may be seen from Table 2, the leading crops under rotation, such as spring wheat, sunflower and corn, give their yield almost exclusively as a result of winter precipitation. This is why the accumulation and maximum conservation of this type of precipitation is one of the most important problems of local field management.

Hydrological investigations of river basins showed that the mean spring runoff in the syrt portion of the Trans-Volga region is 50% and that on the right bank of the Volga River is 60% including that in the basin of the Khoper River which is 75% of the total snow precipitation. Direct observations on the utilization of melt water by soil in the field indicate that these data are too high.

During 11 years the Southeastern Agricultural Institute conducted studies of the melt

¹ Pochvovedeniye, 1957, No. 2 and 1960, No. 1.

WATER BALANCE AND MOISTURE CYCLE

Table 1
Available water contents

Crop under rotation	Number of years of observation	Number of borings	Mean storage in spring	Including winter precipitation	
				in mm	in %
Spring wheat + grasses	14	51	170	107	62,8
Perennial grasses cut in the 1st year	12	45	160	122	76,3
Perennial grasses cut in the 2nd year	12	57	100	65	64,8
Spring wheat on after sod	13	57	157	159	100
Same, used in crop rotation	13	48	147	123	83,2
Black fallow	14	66	129	69	53,8
Winter wheat	9	39	155	35	22,8
Row crops	17	78	151	138	91,2
Dark bread grins	14	48	148	68	44,2
Black fallow	12	39	173	93	53,4
Winter wheat	13	48	203	27	13,4
Aver. aft. soil plowed in autumn aft. sod	14	387	153	109	71,2
Average after winter wheat	11	87	184	37	20,1
Average after perennial grasses	12	108	130	93	71,7

Note: Comma represents decimal point.

Table 2
Water used by crops from the water storage in the upper 150 cm of the soil

Crops under rotation	Mean from 1941-1952 from the storage in the soil, mm	Including that from winter precipitation, %
Spring wheat + grasses	134	79,7
Grasses cut in the 1st year	154	79,0
Grasses cut in the 2nd year	94	69,1
Spring wheat after sod	102	100,0
Same, under crop rotation	96	109,0
Winter wheat on black fallow	135	26,2
Row crops	150	92,2
Dark bread grains	93	67,0
Winter wheat after black fallow	145	18,8

Note: Comma represents decimal point.

water runoff in a small catchment of 17 ha covered 61.5% by fields plowed in the late autumn, 34.5% by winter crops, and 4.0% by other crops. The soil in the area is southern Chernozem. Runoff was determined by using the water of Bazin-Hegli. Under these conditions the mean runoff coefficient was 0.37, varying from 0.0-1.0 from year to year.

A number of investigators, including Lachin-ov (19), Sharov (30), Mosolov (21), Sergeyev (5), and others, believe that moist soil when frozen is impermeable to water. This opinion is not substantiated by our studies of the

water regime in the autumn, winter, and spring of 1945-1946 and 1946-1947. On the contrary, we found that to a certain degree melt water and rain penetrate frozen soil to a considerable depth. The results of our investigations agreed with the conclusions of Shalabanov (29), Kachinskiy (13), and Kuznik (17) that frozen soil is permeable to water; only in rare cases is soil impervious to water when it is in the form of liquid mud.

Using the dilatometric method, Andrianov (1) established that under field conditions unfrozen water in the soil amounts to a multiple of 1.5-3.5

of maximum hygroscopicity. Investigators at the Physical-Agronomy Institute (3) proved that free water can crystallize only at a temperature corresponding to the cryohydric point. However, even at this temperature not all water freezes, part of it remains in a super-cooled state.

During the whole 23 years of field observations at Saratov only one case was recorded (1929) when melt water runoff was 100% of the water content in the snow. In other years meltwater was absorbed to varying degrees by the soil in spring. Long-period data on meltwater runoff over various types of crop rotation are summarized in Table 3.

24 m³/ha of fertile soil under the foregoing conditions of crop rotation. Meltwater runoff is the most important factor in erosion in the Southeast.

Scientific and practical experience in the Southeast indicates that the soil moisture content of the root zone could be increased to maximum field capacity by controlling snow retention and meltwater runoff, and this is an important factor in crop yield under arid conditions. Liquid precipitation during the growing period amounts to 41% of the annual total and is an additional factor for the increase in crop yield.

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Table 3
Runoff coefficient in fields under crop rotation

Years	Field plowed in the autumn	After sod	Perennial grasses
Mean from 1941-1952	0,41	0,17	0,41
With the preceding wet autumn	0,60	0,26	0,63
With a preceding dry autumn	0,32	0,10	0,29

Note: Comma represents decimal point.

The magnitude of runoff is influenced by the nature of the slope, snow depth, melting intensity, soil tillage, etc. No matter how important the foregoing factors are, soil moisture from autumn on and the structural condition of the plowed layer have the greatest influence on runoff. As may be seen from Table 3, the nature of soil moisture in the preceding autumn had a pronounced effect on the utilization of meltwater by the field plowed in the late autumn and a lesser effect on the utilization of meltwater by plowed sod land. Development of grass stand also had an effect on runoff over perennial grasses in individual years.

The 12-year mean (1941-1952) water content in the snow cover in the field under multiple crop rotation (11) was 112.5 mm and the meltwater runoff during this period was 34.8 mm. In the preceding 12 years (1927-1938) the loss from meltwater runoff averaged 28.5 mm in the catchment area. On the basis of many years of study, Kabanov (12) also concluded that "runoff over southern chernozem soils (Saratov) averages 35.1 mm, or an amount of water equal to the monthly total precipitation during the growing period."

Observations were also made on soil erosion during meltwater runoff over southern chernozem under crop rotation having a slope of 0.016. The amount of soil eroded in the field plowed in the late fall fluctuated 13.9 to 43.5 m³/ha under various crops. Judging by preliminary calculations, meltwater runoff erodes on the average

Institute and the Krasnokutsk Experiment Station found that liquid precipitation in spring is fully utilized by winter and early spring crops. Summer precipitation is less effective in this respect, but increases atmospheric humidity, thus reducing evaporation from the soil surface.

As investigations in areas of ordinary and southern chernozem have shown, all liquid precipitation in the spring, summer, and autumn is absorbed by the soil, except for rare occasions. Losses of liquid precipitation are due partly to its retention by the leaf surfaces (an average of 43 mm during the growing period) and primarily to evaporation from the soil surface.

1937 was distinguished by showers of varying intensities. Investigations were conducted at the experimental field on the utilization of these showers in fields under fallow row-crop rotation. The soil was southern chernozem and the slope was 0.016. Precipitation was measured with a rain gage installed in the field (Table 4).

Data in Table 4 show that in most cases shower precipitation could be found in the soil at a slope of 0.016. There was less absorbed water under crops during the second part of the growing period, which is attributable to the retention of precipitation by leaves. The shower of June 9 was not fully absorbed by soil in black fallow. No soil erosion was recorded during the entire period of observation on the

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Table 4

Absorption of rain shower by soil in 1937

Date of shower	Amount of rain, mm	In fields under crop rotation			
		Black fallow	Spring wheat	Winter wheat	Sunflower
Apr. 28	22,7	19,3	19,2	25,7	15,6
May 16	22,7	21,1	18,8	14,3	17,4
June 9	38,8	28,5	34,4	35,1	33,3
July 10	14,4	14,2	10,3	Not observed	5,1

Note: Comma represents decimal point.

lization of showers of varying intensities in 1937. On June 14, 1938, there was a shower of great intensity. The rain was almost fully absorbed by the soil under spring wheat after the harvest, while under an annual crop of spring wheat the loss of this water amounted to 15.1 mm.

Rains of very great intensity are a rare occurrence in the Southeast. Such rain fell on July 20, 1941, and amounted to 61.4 mm in a day, including 44.8 mm in 18 minutes. Observations showed, only the land after plowing of sod absorbed this precipitation entirely. In other areas of crop rotation runoff was 34-40 mm. In this case soil erosion on black fallow was very pronounced.

N. M. Tulaykov and Murashko (27) recorded rain in Saratov in 1924 which amounted to 120 mm in 45 minutes. The rain absorbed by the soil was 67.5%, and under winter rye, 85%. Dubakh (7) studied runoff from the rain in the Voronezh Agricultural Institute from 1926-1927. In a field with a slope of 0.08 almost all precipitation was absorbed by the soil. Only on a slope of 0.4 did runoff occur during rains exceeding 30 mm. Vysotskiy (6) arrived at similar conclusions; he described an intense shower on August 11, 1894, which amounted to 120 mm in less than an hour. "Such rains," he wrote, "as meltwater runoff, have a strong erosive effect on the soil surface, especially in fields and on roads."

In the Southeast, where very intense showers are rare, their erosive effect is limited primarily to the Volga elevation. The main source of losses of rain here is evaporation from the soil surface.

Under conditions prevailing in the Southeast, where ground water is deep and has a pulsive horizon almost everywhere, water losses from a bare soil surface are determined by the differences in soil moisture at certain intervals. Investigations by this method showed that the greatest losses by evaporation from the soil surface in unit time occur in the early spring between the time of snow melting and the time of sowing. According to the data of the author and the meteorological bureau of the Southeastern Agricultural Institute, these losses vary from 14-95 mm for various years and for different crops under rotation. Long-term data indicate that they average 35 mm.

Under conditions prevailing in the Southeast, autumn precipitation is fully absorbed by the soil. The coefficient of its conservation from evaporation varies from 0.28-0.78. Precipitation losses after the harvest amount to 100% in August, 70% in September, and 15%-20% in October-November of the total precipitation during this period. During 11 years of observation in Saratov, losses by evaporation averaged 52%, or 72 mm of precipitation during the post-harvest period.

It is more difficult to determine evaporation from the soil surface under vegetation. The methodological difficulty consists in that these losses occur parallel with the utilization of water by plants. The losses are determined by: 1. The mulching of an area with straw and asphalt and measuring soil moisture in mulched and non-mulched plots, adding a correction for the accretion of dry matter from spring wheat. Evaporation from the soil surface, excluding that from plants, was calculated according to the following formula:

$$X = P - \frac{c \cdot d}{e},$$

where X is the loss of water by evaporation from the soil surface without counting that from plant; P, total water losses from the root zone (including water used by plants) in non-mulched plots; c, the accretion of dry matter on non-mulched plots; d, water used by plants in non-mulched and mulched plots and e, accretion of dry matter on mulched plots. 2. By the lysimetric method, by installing Popov lysimeters with and without plants among the vegetation. The observations on evaporation were made before the coverage by herbs was complete. This period corresponds to the period when the soil surface is shaded and the plowed layer is dry. The total water losses by evaporation from the soil surface excluding that from plants before their closing, was for the years of observation:²

67.3 mm from April 10-May 27, 1937
63.1 mm from April 22-May 29, 1938
55.0 mm from April 8-May 17, 1939

²In 1938 and 1939 candidates of the agricultural meteorological laboratory of P. D. Yakunin took part in the work.

These data show that losses by evaporation from the soil surface in the period after sowing to the closing of plant canopies are similar from year to year, even though weather conditions in these years varied greatly. We do not feel that the given data are exhaustive, but in the absence of more perfect methods they may serve as a guide for the construction of a water balance.

After the appearance of the known works of Lebedev (18), great importance was given to condensation processes as an additional source of water supply to plants. Our investigations showed that in summer soil surface temperature in fallow drops below air temperature during a few hours at night. However, at a depth of 2 cm and in the lower microlayers of the plowed horizon the temperature is considerably higher than that at the soil surface and in the air at these hours, which is characteristic of temperature distribution of the radiational type.

The daily temperature of the plowed layer under vegetation and that of its surface is always lower than the air temperature. Maxi-

mum vapor pressure in the air of the soil in all microlayers of the plowed horizon is always higher than absolute atmospheric humidity in summer, including the hours of maximum cooling of the soil surface. The absolute humidity of the air layer near the ground under vegetation is higher than the maximum vapor pressure in the plowed horizon during the day and lower at night when transpiration is least.

Moisture changes in the plowed horizon of black fallow in the evening and morning are given in Table 5.³ An increase in the moisture of the upper microlayers of the plowed horizon at sunrise was accompanied at all periods of observation by its pronounced decrease in the lower-lying microlayers.

During very dry periods, when the soil in the condensers dried up to the air-dried state, moisture increased from 0.004 to 0.1 mm at night. When, however, soil moisture was at the limit or higher than maximum hygroscopicity,

³ Candidate L. A. Zapasnikova took part in the work.

Table 5
Soil moisture — mean from 10 borings, %

Date of observa- tion	Time of day	Depth, in cm				
		0-2	2-5	5-10	10-20	20-30
1 9 3 7						
June 27	Sunset	4,8	26,5	27,3	28,2	29,8
June 28	Sunrise	5,3	27,4	27,5	28,1	28,9
		+0,5 ^a	+0,9	+0,2	-0,1	-0,9
1 9 4 8						
May 11	Sunset	7,6	24,2	30,8	30,5	30,6
May 12	Sunrise	8,3	25,7	30,8	29,8	29,7
		+0,6	+1,5	+0,0	-0,7	-0,9
May 12	Sunset	5,8	23,3	29,5	30,5	30,0
May 13	Sunrise	6,7	24,8	28,9	29,1	29,5
		+0,9	+1,5	-0,6	-1,4	-0,5
May 13	Sunset	6,0	22,7	28,3	29,8	29,8
May 14	Sunrise	7,2	23,3	28,4	28,9	28,6
		+1,2	+0,6	+0,1	-0,9	-1,2
June 24	Sunset	5,1	8,4	23,8	28,9	29,4
June 25	Sunrise	5,9	9,8	23,8	28,0	29,1
		+0,8	+1,4	+0,0	-0,9	-0,3
June 25	Sunset	4,0	6,8	22,5	28,6	29,9
June 26	Sunrise	4,9	8,5	23,0	28,1	29,1
		+0,9	+1,7	+0,5	-0,5	-0,8
June 26	Sunset	3,9	6,1	22,0	28,1	29,8
June 27	Sunrise	4,5	8,3	22,9	27,6	29,0
		+0,6	+2,2	+0,9	-0,5	-0,8
Nov. 2	Sunset	35,5	35,3	36,1	33,5	33,8
Nov. 3	Sunrise	39,0	36,0	34,8	33,0	33,1
		+3,5	+0,7	-1,3	-0,5	-0,7

^a Plus and minus — increase or decrease of moisture during night hours.

Note: Comma represents decimal point.

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evaporation at night varied from 0.07-0.14 mm, and dew formed. Apparently dew forms as much from atmospheric vapor as from diurnal evaporation from the plowed layer.

The summary of information collected in the Southeast does not give any reason to believe that condensation plays a role in water accumulation. Actually the only source of water supply to cultivated plants is atmospheric precipitation from which only 150 mm, or 4% of the total is directly utilized by plants. Crop yield may be increased by eliminating part of the losses. The mean long-period water balance is as follows: of the 390 mm precipitation 150 mm are used by plants; 240 mm are lost in the form of meltwater runoff and evaporation in the pre-sowing period; 150 mm fall in the form of fine precipitation which evaporates; 5 mm are lost on evaporation from the soil surface under plants, and 72 mm on evaporation in autumn.

Conclusions

1. The decisive role is played by winter precipitation in the water balance and water supply to cultivated plants in the Southeast. Its share in the water reserves of fields plowed in the fall and plowed sod land is more than 70%. The major crops under rotation, such as spring wheat, sunflower and corn, owe their yield almost entirely to winter precipitation.
2. In erosion, the principal role is played by meltwater runoff, which according to long-period data averages about 35 mm and erodes about 24 m³/ha of soil annually.
3. Rain in spring, summer, and autumn is almost entirely adsorbed by the soil. Its influence on erosion is limited in the majority of cases to the Volga uplands. The main source of losses of summer and autumn precipitation is evaporation.
4. The sum of accumulated information does not give any reason to assign a role to condensation in the accumulation of soil moisture. Actually the only source of the water supply to plants in the Southeast is atmospheric precipitation.
5. Moisture losses on evaporation in the Saratov region include: 35 mm during the period from snow melting to sowing; 55-63 mm in the period from sowing to the closing of plant canopies in rows; 72 mm during the post-harvest period to the disappearance of snow from fields plowed in autumn; and 43 mm as a result of evaporation of precipitation from the surface of leaves. Cultivated plants use 150 mm directly.

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INFLUENCE OF FERTILIZERS ON THE PROPERTIES OF SOD-PODZOLIC SOILS

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As known, fertilization has a great influence on the chemical, microbiological, and other processes taking place in the soil. The influence of fertilizers on the properties of soil increases the more when they are applied systematically.

Organic fertilizers usually improve the properties of soil. Mineral fertilizers, when properly used, also promote fertility. The nutrient contents increase under the influence of mineral fertilizers, yield increases, and the amount of root and stubble residue increases. The amount of nutrients and manure which is added to the soil greatly improves its physical, chemical, microbiological, and other properties, i.e., greatly increases productivity. However, not all mineral fertilizers act in the way described and not always so. Some of them, especially when systematically applied in the same amount, deteriorate the properties of acid sod-podzolic soils.

Taking the foregoing into account, we made a series of field and laboratory investigations in the last ten years on the influence of various fertilizers on the properties of sod-podzolic soils. There are a number of studies on this problem, made both in the Soviet Union and abroad. The studies made by S. V. Shcherba at the Pryanishnikov Dolgoprudnaya Agricultural Chemical Station are especially worth mentioning. However, the problem of the influence of fertilizers on soil properties needs further investigation.

In order to study the problem of the influence of fertilizers we took soil samples from an experimental area established by D. N. Pryanishnikov in 1912 at the site of the Timiryazev Agricultural Academy. At the time the samples were taken, fertilizers had influenced the soil for 38 years. The effect of fertilizers was studied in a six-crop rotation. The following amounts and types of fertilizers were used: annual applications of 7.5 kg/ha of nitrogen, 15 kg/ha of P_2O_5 , 22.5 kg/ha of K_2O , and 20 metric tons/ha of manure from 1912-1938. Thus, in the first 26 years the amounts applied were: 195 kg/ha of nitrogen, 300 kg/ha of P_2O_5 , 5 kg/ha of K_2O , and 468 metric tons of manure. Since 1938 the amounts of mineral fertilizers were increased to 75 kg of nitrogen, 15 kg of P_2O_5 , 90 kg of K_2O , and 20 metric tons/ha per year. Phosphorous fertilizers are applied in the form of superphosphates,

and potassium fertilizers in the form of 40% potassium salt and potassium chloride. Before 1938 nitrogen fertilizers were applied in the form of Chile and Norwegian saltpeter and since 1938, in the form of ammonium sulfate.

Part of the results obtained are given in Table 1. As may be seen from this table, individual fertilizers differ greatly in their effect on the chemical properties of soil. Under the influence of manure the total hydrolytic acidity decreased sharply, the sum of adsorbed bases, and the degree of saturation increased almost three times, the content of humus, nitrogen, and available forms of phosphorus and potassium increased, while the content of mobile forms of aluminum decreased to a harmless minimum. There was no more necessity of liming this soil.

Mineral fertilizers differ greatly from manure in their action on acid sod-podzolic soil. Under the influence of nitrogen and nitrogen-potassium fertilizers hydrolytic acidity increased, the sum of adsorbed bases, and the degree of saturation increased, and the amount of mobile forms of aluminum and manganese increased almost three times. Superphosphate, applied without other fertilizers, had no significant influence on the acidity of the soil, but against a background of nitrogen-potassium fertilizers it slightly decreased hydrolytic acidity, decreased the content of mobile forms of aluminum, and increased the sum of adsorbed bases. Potassium fertilizers increased hydrolytic acidity and the content of mobile forms of manganese, but had no influence on the amount of mobile forms of aluminum. Phosphorus, against a background of nitrogen-fertilizers, lowered the content of mobile forms of manganese.

The change in soil properties under the influence of a prolonged application of fertilizers was also studied by us in field experiments at the Agrobiological Station of Moscow University. One of these tests was begun in 1950, the second, in 1951. Both tests were made on acid sod-podzolic soil which was slightly cultivated. In the first experiment soil was taken for analysis after fertilizers had acted on it for seven years, in the second experiment, the soil was under the influence of fertilizers for three years. Fertilizers were applied in both experiments in the form of ammonium sulfate

Table 1

Influence of the systematic use of fertilizers on the change in soil properties. Results of analysis of samples taken from D. N. Pryanishnikova's experiment

Experimental setup	pH of salt extract	Hydrolytic acidity	Sum of adsorbed bases	Degree of saturation, %	Al	Mn	Humus (det. by Tyurin's method)	Total nitrogen	P ₂ O ₅	K ₂ O
		in meq/100 g of soil			in mg/100 g of soil			in percent	in mg/100 g of soil	
O (without fertilizer)	4,6	5,9	2,3	28	10,2	3,2	2,9	0,13	2,4	4,0
N	4,6	6,5	1,8	22	28,0	5,7	2,9	0,15	2,4	5,0
P	4,6	5,9	3,4	34	—	—	2,8	0,13	5,7	3,9
K	4,6	6,3	3,0	32	7,8	4,6	2,5	0,11	2,4	8,0
NK	4,4	6,6	0,53	7,3	30,0	9,2	2,8	0,12	2,4	8,0
NPK	4,6	6,4	1,3	17	7,8	4,7	2,9	0,15	4,8	5,7
Manure	6,0	2,3	6,0	72	0,39	1,5	3,2	0,17	7,0	10,0

Note: Comma represents decimal point.

during the first three years, and in the form of ammonium nitrate thereafter. Potassium and phosphorous fertilizers were applied during the entire period in the form of potassium salt and superphosphate in amounts of 90 kg/ha nitrogen and K₂O, and 60 kg/ha of P₂O₅ in the first experiment, and 60 kg/ha of each in the second experiment. The results of the soil analysis are given in Tables 2 and 3.

Table 2 shows that the application of nitrogen fertilizers (in the form of ammonium) and potassium chlorides lead to an increase in the total hydrolytic, and exchange soil acidity. In addition to this, the amount of mobile forms of aluminum and manganese increased in the soil under the influence of nitrogen and the sum of adsorbed bases and the degree of saturation decreased. Besides, under the influence of nitrogen and potassium fertilizers, the content of adsorbed calcium and magnesium decreased noticeably. All this, of course, deteriorates the properties of the soil. Phosphorous fertilizers (superphosphates), introduced against a background of nitrogen-potassium fertilizers, moderated the negative effects of nitrogen and potassium fertilizers on soil, but did not eliminate them completely.

In the second experiment mineral fertilizers were added against the background of acid soil and on the same soil to which lime was added in proportion to hydrolytic acidity only, and manure was added at a rate of 30 metric tons/ha. Table 3 shows that mineral fertilizers added to non-limed soil had the same effect on it as in the previous experiments.

A different picture is presented when mineral fertilizers were applied against a background of lime and manure. In this case nitrogen and nitrogen-potassium fertilizers did not increase the total exchange and hydrolytic acidities. There were no mobile forms of aluminum against a background of lime and there was very

little mobile manganese. Thus nitrogen and nitrogen-potassium fertilizers deteriorate the properties of acid soils and have little effect on limed soil.

During a number of years we studied the effect of nitrogen and potassium fertilizers on soil properties as dependent on its degree of cultivations under-conditions of pot experiments. The experiments showed that nitrogen and potassium fertilizers have either no negative effect or a very slight effect on well-cultivated soil (which was given manure for a long time).

The effect of fertilizers on the properties of soil depends on their form. Ammonium fertilizers differ greatly in their effect from nitrate fertilizers.

Lately liquid nitrogen fertilizers have been used in the Soviet Union and in a number of other countries. The question arises — what effect do liquid nitrogen fertilizers have on soil as compared to solid nitrogen fertilizers? The liquid nitrogen fertilizer most widely used in the USSR is ammonia water, which is alkaline. One may assume that when ammonia water is applied to acid soil the reaction of the medium would change toward alkalinity. This actually took place immediately after the application of ammonia water, but then the situation changed. To study the influence of ammonia water on soil properties, both field and pot experiments are being conducted at the Agrobiological Station of Moscow University. The field experiments are conducted on acid, slightly cultivated soil, and on the same soil to which lime is added. Nitrogen fertilizers are applied at the rate of 100 kg/ha of active substance. Of the many experiments conducted in the last four years we only give data on the influence of various forms of nitrogen fertilizers on changes in soil properties (Table 4).

Table 4 gives data on the analysis of soil

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Experimental setup	Agricultural-chemical soil indices													
	pH of salt extract	Hydrolytic acidity, meq/100 g of soil	Exchange	Al in mg/100 g of soil	Mn	Sum of adsorbed bases, meq/100 g of soil	Degree of saturation %	Ca		Nitrogen	Humus, % (determined by Tyurin's method)	P ₂ O ₅	K ₂ O	
								Adsorbed in meq/100 g	Total, %					
														Hydrolyzed, mg/100 g
Without fertilizers	4.4	4.7	0.77	6.9	1.72	4.4	48.3	2.70	0.90	0.09	1.88	5.5	3.80	
Nitrogen	4.3	6.0	1.35	12.5	4.4	3.5	36.8	1.83	0.85	0.12	—	5.5	3.80	
Potassium	4.4	4.9	1.04	9.5	2.9	3.5	41.6	2.17	0.90	0.10	1.95	6.2	4.75	
Nitrogen-potassium	4.2	6.2	1.26	12.0	8.3	3.8	40.0	1.92	0.84	0.10	2.00	5.5	4.75	
Full fertilizer (NPK)	4.4	5.1	1.15	10.1	7.7	3.8	41.7	3.14	0.90	0.10	2.04	11.9	4.75	

Note: Comma represents decimal point.

acidity before the experiment and two years after the experiment was started during which 200 kg/ha of nitrogen had been added to the soil. As might have been expected, the chemical properties of soil deteriorated under the influence of ammonium sulfate and improved under the influence of sodium nitrate. Ammonia water deteriorated the properties of acid soil, but to a lesser degree than did ammonium sulfate. Under the influence of ammonia water the hydrolytic and exchange acidities increases, the sum of adsorbed bases decreased, and the content of mobile forms of aluminum and manganese increased greatly. Not only ammonia water, but also ammonium sulfate had little effect on the properties of limed soil.

Ammonium forms of nitrogen and potassium chloride deteriorate the chemical properties of acid soils, as shown previously. As a result of this, the amount of available forms of certain microelements and also the magnesium content may decrease. Direct soil analyses showed that after nitrogen and nitrogen-potassium fertilizers have been used for seven years, the amount of adsorbed magnesium in the soil decreased. Unfortunately there are no reliable methods at the present time which would allow determination of the amount of molybdenum which is available to plants in the soil. With this in view, we conducted pot experiments to study the effectiveness of magnesium and molybdenum. For this purpose, soil was taken from two experimental field plots, a control plot where no fertilizers were used and an NK plot to which nitrogen and potassium fertilizers were applied for eight years. The results of pot experiments with spring wheat are given in Table 5.

Table 5 shows that the addition of molybdenum and magnesium to the non-fertilized soil had no significant effect on the yield of wheat. On the other hand, the addition of molybdenum to the soil which was receiving nitrogen and potassium fertilizers for eight years increased the grain yield of spring wheat by 25%, and the addition of molybdenum together with magnesium increased yield by 46%. These experiments have shown that the systematic application of ammonium nitrogen fertilizers and potassium chlorides may lead to the impoverishment of available forms of magnesium and molybdenum in acid soils.

Parallel with the studies on the effect of fertilizers on the chemical properties of soil, we conducted a series of experiments on the effect of fertilizers on microbiological processes in the soil.

The effect of a prolonged use of fertilizers on microorganisms in the soil was studied at the Agrobiological Station of Moscow University.

Microbiological analyses were made during several years. The microorganisms studied included: ammonifiers, aerobic cellulose decomposing bacteria, *Azotobacter*, *Clostridium pasteurianum*, and oligonitrophiles. The analyses were made by the method recommended at the All-Union Conference on Soil Microbiology (December 1953).

The results of soil analysis obtained after four years of experimentation are given below.

Table 3

Influence of 3 years' use of mineral fertilizers and lime on the change in properties of sod-podzolic soil

Fertilizer	pH of salt extract	Ex-change	Hydrolytic	Degree of saturation, %	Al	Mn	Ca
		Acidity			in mg/100 g of soil		
		In meq/100 g of soil					
Without fertilizers	4,6	0,87	5,59	43,0	7,8	3,8	2,6
Nitrogen	4,6	1,24	6,36	48,8	11,0	3,2	2,1
Potassium	4,6	1,08	6,11	37,0	9,7	2,8	3,0
Nitrogen-potassium	4,6	1,12	6,32	25,9	10,1	3,8	2,7
Full mineral fertilizer (NPK)	4,6	0,91	5,72	41,2	8,2	3,1	2,9
Lime	6,6	0,0	2,56	63,3	0,0	Trace	4,0
Lime + nitrogen	6,4	0,0	1,71	84,6	0,0	"	4,7
Lime + potassium	7,0	0,0	1,72	86,1	0,0	"	6,3
Lime + nitrogen-potassium	6,8	0,0	1,72	84,0	0,0	"	6,0
Lime + full mineral fertilizer (NPK)	6,8	0,0	1,94	82,6	0,0	"	6,0

Note: Comma represents decimal point.

Table 4

Influence of various forms of nitrogen fertilizers on the change in soil properties

Treatments	Hydrolytic	Exchange	pH of salt extract	Degree of base satura- tion, %	Mn	Al
	Acidity				in mg/100 g of soil	
	In meq/100 g of soil					
Soil before the addition of fertilizers, 1956						
Without fertilizers	5,27	0,88	5,0	52,2	0,33	7,7
Soil 2 years of applying fertilizers, 1957						
PK (background)	5,70	0,62	5,0	55	0,78	4,94
PK + (NH ₄) ₂ SO ₄	6,74	1,65	5,0	39	7,08	13,77
PK + NH ₄ OH	5,78	1,12	5,0	50	6,65	9,81
PK + NaNO ₃	4,49	0,62	5,2	58	0,65	4,94

Note: Comma represents decimal point.

Mineral fertilizers were applied to acid, slightly cultivated soil, (pH 4.6) and to the same soil to which lime was added in proportion to hydrolytic acidity, manure was applied at a rate of 30 metric tons/ha. The results of microbiological analyses made during the study of the effect of four years' use of fertilizers on various groups of microorganisms are given in Table 6. Soil samples were taken seven times in the summer, in May, June, July, August, September, October, and November. Table 6 gives the averages of the seven determinations. These data show that lime and manure sharply increase the intensity of microbiological processes in the soil. Phosphorous fertilizers on acid resulted in the increase of

the number of ammonifiers, while potassium and nitrogen-potassium fertilizers decreased the number of ammonifiers considerably.

The number of oligonitrophiles changed little under the influence of mineral fertilizers, but increased about 1.5 times under the influence of lime and manure. *Azotobacter* was absent in all treatments, while the nitrogen-fixing *Clostridium pasteurianum* was found in comparatively large quantities in all plots. The application of fertilizers had a great effect on the amount of *Cl. pasteurianum*. Nitrogen, potassium, and nitrogen-potassium fertilizers suppressed the life activity of *Clostridium*, while phosphorous fertilizers stimulated it

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Table 5

Influence of magnesium and molybdenum on the yield of spring wheat
(pot experiment)

Experimental setup	Soil from the non-fertilized plot		Soil to which nitrogen and potas. fertilizers were applied during 8 years	
	g per vessel	In %	g per vessel	in %
Background (NPK)	7,5	100	5,4	100
" + molybdenum	7,4	98	6,8	125
Background + molybdenum + magnesium	8,3	111	7,8	146

Note: Comma represents decimal point.

Table 6

Influence of fertilizers on the number of microorganisms in soil

Treatments	Ammonifiers, million per g of soil	Oligonitrophiles, thousands per g of soil	<u>Clostridium pasteurianum</u> , thousands per g of soil	Nitrifiers, thousands per g of soil	Intensity of cellulose decomposition (number of decomposition spots)
In acid soil					
Without fertilizers	2,16	41,9	32,0	21,8	163,8
N	2,41	31,1	13,5	12,5	96,1
K	1,17	34,2	15,9	179,7	140,3
NK	1,17	49,8	24,7	167,0	39,0
NPK	3,77	39,0	118,1	334,4	113,3
Against a background of lime and manure					
Without fertilizers	2,41	58,7	202,1	164,8	176,5
N	3,28	63,2	75,7	702,5	213,1
K	1,31	70,7	173,0	589,5	215,1
NK	5,66	64,6	140,0	847,6	255,8
NPK	7,23	64,5	229,4	547,0	212,0

Note: Comma represents decimal point.

greatly. The application of lime and manure increased the Clostridium content in soil 2 to 0 times.

Fertilizers had a great effect on the amount of nitrifiers. Nitrogen fertilizers on acid soil decreased the amount of nitrifiers, while they increased it greatly on limed soil. Potassium fertilizers sharply increase the amount of nitrifiers both in acid and limed soil. Phosphorus fertilizers had a strong positive effect on nitrifiers in acid soil.

Nitrogen and nitrogen-potassium fertilizers sharply lowered the process of decomposition of cellulose in acid soil. Phosphorous and potassium fertilizers had no significant effect

on cellulose decomposing bacteria. Lime and manure increased the activity of cellulose decomposing bacteria.

Experiments were conducted at the Agro-biological Station of Moscow University on the cultivation of acid sod-podzolic soils. The means for cultivating soil included the use of lupine, lime, manure, and liquid peat compost. During three years of this experiment microbiological analyses were made on the content of various groups of microorganisms. Of the many analyses made, data are given (Table 7) only on those which pertain to the influence of various fertilizers on the number of Cl. pasteurianum.

Soil was analyzed for its Cl. pasteurianum

Table 7

Influence of fertilizers on the amount of Clostridium pasteurianum, thousands per g of soil

Treatment	Number of cells
Without fertilizers	7,68
Lupine as a green manure	56,7
Compost, 40 metric tons/ha	119,6
Manure, 40 metric tons/ha	120,3
Organo-mineral mixture of 3 cntr/ha of superphosphate, 3 metric tons of compost and 3 cntr/ha of lime	11,86

Note: Comma represents decimal point.

content five times in summer and the mean data obtained are given in Table 7. Compost and manure were used against a background of lime, applied in proportion to hydrolytic acidity.

Table 7 shows that the application of peat compost and manure against a background of lime increased the amount of Cl. pasteurianum about 15 times. Lupine, used as green manure, also sharply increased the amount of Cl. pasteurianum. Azotobacter was absent in all treatments.

The toxic properties of bacteria and fungi were determined from the effect of their suspensions on the sprouting of seeds, the initial development of wheat, and the development of the Azotobacter. To determine the toxicity of microorganisms, wheat seeds were kept for 24 hours in a liquid culture or in a bacterial suspension. Control seeds were soaked in water and in a sterile beef peptone broth.

Of the 143 pure cultures of bacteria extracted from the soil, 42 strains were toxic. Under the influence of these strains, the sprouting, root growth, and initial growth of wheat were greatly retarded. It must be noted that the greatest amount of toxic forms were found in acid soils to which ammonium forms of nitrogen were added. Thus, an analysis made on May 17 revealed that the amount of toxic forms in non-fertilized acid soil was 13% of the total number of colonies, while that on the same soil to which ammonium forms of nitrogen were added, was 26%, and that in soil to which a complete fertilizer was added against a background of lime there were only 3% of toxic forms of bacteria. An analysis on August 8 of the control plot revealed the presence of 14% of toxic forms, 21% when nitrogen fertilizers were used, and 7% when a complete fertilizer was used against a background of lime.

The investigations showed that among the toxic forms, a large part consists of various forms of the genus Bacillus and Bacterium. Bacillus mesentericus was frequently found among spore-formers of toxic bacteria. They were also found among the B. cereus.

Many forms of fungi also have a toxic effect

on higher plants and useful microorganisms (investigations by T. G. Mirchink¹). These fungi develop well in acid soils. An especially large number of toxic forms of fungi develops in acid sod-podzolic soils when ammonium forms of nitrogen are added to them.

According to the data of T. G. Mirchink (Moscow State University), the total amount of fungi was 11,600 per g of soil in our experimental samples taken on June 23 from non-fertilized acid soil, 25,300 per g of soil taken from plots with ammonium nitrogen, and 9,200 per mg of soil taken from plots with lime and manure. A similar picture was observed for samples taken July 21, when 60,000 fungi per g of soil were found in non-fertilized soil, 138,000 per g of soil taken from the plot to which ammonium nitrogen was added, and 36,000 per g of soil taken from the plot to which lime and manure were added. T. G. Mirchink isolated fungi in pure culture and tested their toxicity on the basis of the sprouting of wheat seeds. The number of toxic forms of fungi in acid soil was 32%, and that in the soil to which lime and a full mineral fertilizer was added was 15%.

Detailed study of the species composition of toxic forms of fungi showed that the largest amount is represented by species of the genus Penicillium, Fusarium and Trichoderma. Especially toxic are: P. cyclopium Weste, P. nigricans Thom and others. The liquid culture of these fungi suppressed the sprouting of wheat seeds, the initial growth of its roots and that of its seedlings either fully or to a great extent.

Thus, the systematic application of ammonium forms of nitrogen fertilizers separately and in combination with potassium chlorides to acid sod-podzolic soils not only deteriorates their chemical properties, but also results in the accumulation of toxic microorganisms in them.

The negative properties of acid sod-podzolic

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soils make the use of such bacterial preparations as azotobacterin useless on them. The tests made by Sushkina (2), Avdonina and Khudjakova (1), and others indicate that when azotobacterin is added to acid soil the Azotobacter dies within 2-3 days after application.

To study the causes of the loss of the Azotobacter in sod-podzolic soils, we added azotobacterin to the soil in the field which was investigated for the effect of mineral fertilizers dependent on liming and the application of manure. The experiment was started in 1951 against two backgrounds: a) without lime and manure, and b) with lime added in proportion to hydrolytic acidity plus 30 metric tons/ha of manure in 1951, and 30 metric tons/ha of manure in 1953. Azotobacterin was applied in 1956, 1957, and 1958. The content of the azotobacter in the soil was determined dynamically each year during the growing period. Experiments of three years' duration showed that the Azotobacter perished within 2-3 days after application in soil without lime and manure. In limed and manured soil the Azotobacter survived 20-40 days in 1956 and 40-60 days in 1957 after the addition of azotobacterin and did not disappear at all in 1958. Soil analyses made in 1959 showed that the Azotobacter added to limed and manured soil in the spring of 1958 was still existent in great amounts of 1959.

After the application of lime and manure, the chemical properties of sod-podzolic soil were favorable to the development of the azotobacter (pH, 6.5, mobile forms of aluminum disappeared, and the amount of organic substances increased as a result of the application of 60 metric tons/ha of manure and the use of perennial grasses). In spite of this, the Azotobacter disappeared in 1956 and 1957.

To find the causes for the disappearance of the Azotobacter, numerous experiments were made on its antagonists. For this purpose agar blocks of soil bacteria from sod were placed in a pure Azotobacter culture. Three days later the size of sterile zones on the Azotobacter plate was determined.

Zones of repressed Azotobacter formed around blocks of many antagonistic bacteria, while many microorganisms did not cause the disappearance of the Azotobacter. Part of the results obtained in these experiments are given in Table 8.

Table 8 shows that some bacteria greatly repress the development of the Azotobacter, while others do not. The greatest repressor of the Azotobacter is the Bacillus mesentericus niger.

In addition, experiments were made on the effect of antagonistic bacteria on the Azotobacter under soil conditions. With this in view, a pure culture of Azotobacter was applied together with antagonistic bacteria to well-cultivated, homogeneous garden soil after sterilization. Three days later the number of Azotobacter cells was counted. The experiments showed that many antagonistic bacteria caused the complete disappearance of the Azotobacter, or a considerable reduction of its numbers. It is interesting to note that the largest amount of bacteria antagonistic to the Azotobacter was found in acid soils to which ammonium forms of nitrogen fertilizers were added. There were much less antagonistic bacteria in limed and manured soil, but nevertheless they survived for a long time and harmed the Azotobacter. Only in 1958, 8 years after liming and the double application of manure, were such conditions created in the soil under which the Azotobacter

Table 8
Antagonistic effect of soil bacteria on the Azotobacter

Bacterial cultures	Diameter of sterile zones in mm by replication						Mean diameter of sterile zones, mm
	1	2	3	4	5	6	
<u>Bac. mesentericus</u> type (No. 103)	0	0	0	0	0	0	0
<u>Bac. mesentericus</u> <u>niger</u> (No. 120/1)	14	16	16	16	14	16	16
<u>Bac. idosus</u> <u>mesentericus</u> type (No. 122/2)	14	16	10	12	14	14	14
<u>Bac. idosus</u> <u>mesentericus</u> type (No. 122/7)	10	10	10	18	12	12	13
<u>Bac. tomentosus</u> (129/7)	0	0	0	0	0	0	0
<u>Bac. calidolactis</u> (No. 105)	14	16	16	16	10	8	14
<u>Bac. agglomeratus</u> (No. 124)	0	0	0	0	0	0	0

could live and multiply. Under the effect of lime, manure, and perennial grasses, a change in the biocenosis of soil occurred as a result of which favorable conditions for the use of the Azotobacter were created. The foregoing material indicates that liming and manuring create favorable conditions for the Azotobacter only after a certain period of time.

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BORON AND MOLYBDENUM IN LATVIAN SOILS

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Boron and molybdenum play an important part in plant nutrition. Boron promotes the synthesis of carbohydrates and protein by plants, improves the conditions of fertilization, and also increases the resistance of plants against drought and high temperatures. Molybdenum plays an important physiological role in the nitrogen exchange of plants and microorganisms; it promotes the fixation of molecular nitrogen in the nodules of legumes and also nitrogen-fixing microorganisms in soil. Molybdenum also effects the synthesis of amino acids, promotes the synthesis of protein, and improves the utilization of nitrogen and phosphorus by plants. Molybdenum is especially effective on acid sod-podzolic soils, where it is in a form which is not readily available to plants.

Boron and molybdenum are widely used in the Soviet Union, as well as Latvian agriculture for increasing the yield of agricultural crops. Boron is added primarily to flax and sugar beet, and also to clover seed plants. As a result of the application of boron, the yield of various agricultural crops increases an average of 20%-30%. At the same time the quality of the yield increases. Molybdenum is added to clover, peas, vetch, and other legumes. The yield of clover and other crops increases by 30%-50% as a result of the use of molybdenum. The protein content of leguminous crops increases, which heightens the nutritive value of the forage. Boron and molybdenum must be added differentially, taking into account the presence of available forms of three microelements in soils. In relation to this, a study was conducted in Latvia on the total contents and available forms of boron and molybdenum in various soils found in the republic, and certain principles determining the availability of these microelements have been established.

Boron. Boron is found in soils in various compounds. The degree of availability of these compounds to plants and microorganisms varies. Plants may take up boron from its water-soluble compounds, as well as compounds which are soluble in weak acids.

Soils developed on ancient marine clays and other sedimentary material are richer in boron than soils developed on morainic deposits. Boron is usually contained in such minerals as tourmaline and datolite, where it

is in forms which are not readily available to plants. Calcium and magnesium boron minerals, such as hydroboracite ($\text{CaO} \cdot \text{MgO} \cdot 6\text{H}_2\text{O}$) and ascharite ($2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$) contain boron in a form which is easily available to plants.

We determined the total contents and water-soluble forms of boron in the soils of Latvia. Boron was determined by the quinalizarin method. Water-soluble boron was determined from soil:water extracts of 1:5. Summarized data are given in Table 1.

Sandy and sandy loams contain less total and water-soluble boron than clay loams and clays.

The sod-carbonate soils of Latvia have a comparatively high amount of boron, as well as sod-podzolic soils developed on boulderless fine clay. The amount of total boron in peat soils varies greatly, from 1.5-23.0 mg per kg of soil. The soils of lowland bogs with well-decomposed neutral peat are richer in boron than soils of acid moss peats.

Less than 2% of the total contents of boron in the mineral soils of Latvia go into a water extract, which indicates that the mobility of boron in these soils is very low. Boron is much more soluble, or mobile, in peat soils, with 2.5%-20% of its total content going into the water extract. Certain peats contain up to 2.0 mg of boron per kg of soil. This indicates that humic substances in the peats bind boron more loosely than mineral soil compounds (primarily Fe and Al).

One may judge the content of total and water-soluble boron in individual genetic horizons of Latvian soils from data of Table 2.

The given data show that the distribution of total boron in individual genetic soil horizons is related to their texture and humus content.

Five-textured soil horizons contain more boron than horizons consisting of sand and sandy loam. The humus horizon of soils is richer in boron, as a rule, than other horizons. The distribution of total boron is rather uniform in peat soils. All this is also true for water-soluble boron.

The peat horizons of bog soils contain a

Table 1
Content of total and water-soluble boron in Latvian soils (3)

Soil	Content of B, mg/kg of soil	
	Total	Water-soluble
Sod-podzolic on marine sand	1,5—5,0	0,02—0,04
Sod-podzolic and sod gleyey sandy loams	3,0—10,8	0,02—0,07
Sod-podzolic clay loams and clays	7,7—15,5	0,04—0,12
Sod-carbonate clay loams and peat-podzolic on boulderless fine clays	10,0—35,0	0,08—0,20
Peat soils	1,5—23,0	0,02—2,00

Note: Comma represents decimal point.

comparatively large amount of water-soluble boron. The mineral horizons underlying peat are poor in this form of boron.

What are the factors which determine the availability of boron in the soil? In solving this problem, it was established that plants may take up boron not only from water-soluble solution, but also from compounds soluble in weak acids, to which calcium borate belongs, for instance. However, boric acid forms compounds with aluminum and ferric oxide hydrates which are not readily available to plants.

When the pH increases as a result of liming, the fixation of boron by sesquioxides increases. Humic acids do not give strong and stable compounds with boron. Data on the availability and mobility of boron are given in the form of Scheme 1.

Boron fertilizers are very effective on commercial vegetable, and forage crops on sod-gleyey and dark bog soils of the podzolic zone, as also on acid sod-podzolic soils after liming. The effectiveness of boron decreases, as a rule, on gray forest soils and soils of the chernozem zone.

Molybdenum. Studies on the total reserves of molybdenum and available forms of molybdenum in soils were made at the Soil Biochemistry and Microelements Laboratory of the Academy of Sciences of the Latvian SSR. Total and available molybdenum were determined by the thiocyanide method. Molybdenum available to plants was extracted with oxalate solution at a pH of 3.3 (using the method of Grig).

Average data on the molybdenum content in various Latvian soils are given in Table 3.

The total molybdenum content in various mineral soils of Latvia varies most often from 0.25–2.0 mg Mo per kg of soil. Among peat soils there are individual lowland peats in which the

molybdenum content reaches up to 7.5 mg per kg of soil. This is associated with the conditions of soil formation in the given bogs, the inflow of molybdenum with ground waters as a result of its removal from mineral soils. Sod-podzolic and sod-gleyey sandy soils of the maritime zone of Latvia contain very little molybdenum, from 0.2–0.6 mg Mo per kg of soil.

The content of available or mobile molybdenum is closely related to the total content of molybdenum in the soil. About 5%–10% of the total contents of soil molybdenum are dissolved from mineral soils and upland peats in the oxalate extract.

Molybdenum is in a more soluble form in peats of lowland bogs. An average of about 20% of the total molybdenum content in these soils go into solution in an oxalate extract. In some soils, all molybdenum is in an oxalate-soluble form. The degree of solubility, or mobility, of soil molybdenum depends on the degree of calcium saturation of mineral colloids and humic acids with calcium. The higher the content of exchangeable calcium and calcium humates in the soil, the more mobile is soil molybdenum. This is why bog soils, which contain a large amount of calcium humates, are characterized by the high solubility of molybdenum. Liming of mineral soils also increases the mobility of molybdenum. The same is true to a certain degree of phosphates. All this indicates that molybdenum in the soil is bound primarily by sesquioxides (iron and aluminum).

Data on the molybdenum content in various genetic soil horizons are given in Table 4.

The greatest amount of total and mobile molybdenum is contained in the humus and also in illuvial horizons of podzolic soils. This indicates on the one hand that molybdenum accumulates in the soil together with humus, and on the other hand that during the process of podzol

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Table 2

Distribution of boron in the genetic horizons of various Latvian soils

Soil	Genetic horizon	Depth, cm	Texture	pH KCl	Total humus %	Total boron	Water-soluble boron
						In mg/kg	
Sod-podzolic-gleyey on a two-layered deposit. Livan region	A ₁	1—13	Sandy loam, sand	4,6	8,95	10,0	0,04
	A ₂	14—21	Humified, aggregated sand	4,2	1,85	6,2	0,02
	B	25—35	Clay, gley	4,3	1,79	9,3	Trace
	C	70—80		4,3	0,30	13,6	"
Sod-moderately podzolic sandy loam on boulder clay loam. Dagda region	A _{plw}	0—15	Sandy loam	4,9	1,91	5,0	0,04
	A ₂	20—30	Sand	4,6	0,32	4,1	0,02
	A ₂ B	38—48	Sandy clay loam	4,6	0,27	9,3	0,02
	B ₂	60—70	Clay loam	4,6	0,25	21,7	0,04
	BC	90—100	Same	4,9	0,18	12,4	Trace
	C	115—125	Carbonate sandy loam	7,7	0,13	9,3	"
Strongly podzolized. Illuvial-humus, peaty, sandy. Forest. Ogre region	A ₀	0—5	Slightly decomposed peat	2,7	32,0	—	0,02
	A ₁	5—13	Humified sand	2,9	10,0	2,4	"
	A ₂	18—28	Same, white	4,1	1,82	1,6	"
	B ₁	32—48	Same, brown	4,4	2,45	4,6	"
	BC	38—98	Sand	4,7	0,30	1,5	"
Sod-podzolic, illuvial-humic sandy loam on sand. Forest. Plyavin region	A ₀	0—9	Peat	3,1	58,7	3,6	Trace
	A ₁	10—19	Humified sandy lm.	3,3	4,9	9,3	0,04
	A ₁ A ₂	21—29	Sand	3,9	1,9	6,2	0,04
	B ₁	33—43	Same	4,3	2,5	6,2	0,02
	BC	55—65	Sandy loam	4,7	0,1	3,1	0,03
Sod-carbonate - podzolized, clay on boulderless clay. Forest. Rezeknen region	A ₁	1—12	Clay	4,4	5,66	34,0	0,08
	B ₁	14—22	Same	4,5	1,38	52,7	0,04
	BC	30—40	"	5,6	0,92	46,5	0,09
	C	60—70	"	7,3	0,42	55,8	Trace
Sod-carbonate, typically clay loam on moraine clay loam. Ludzen region	A ₁	0—15	Clay loam	6,8	1,64	10,0	0,11
	C ₁	30—40	Same	7,1	0,32	9,3	0,03
	C ₂	70—80	Carbonate clay - loam	7,4	0,18	7,7	Trace
Sod-carbonate podzolized, sandy gravel on boulder gravel. Rezeknen region	A ₁	2—10	Gravelly sand	4,7	3,28	10,0	0,06
	A ₂ B	10—20	Same	4,2	—	7,5	0,02
	B ₁	20—30	"	5,2	0,51	7,5	0,04
	B ₂	33—43	"	6,2	—	3,1	0,11
	BC	56—73	Sandy gravel	7,4	—	4,6	0,04
	C	76—86	Carbonate gravel	7,5	0,11	1,5	Trace
Sod-carbonate leached on boulderless clay. Forest. Bauska region	A ₁	12—24	Clay loam	6,2	—	18,6	0,07
	AB	28—38	Same	6,2	—	21,7	0,05
	B	45—55	Clay	6,6	—	26,5	0,07
	BC	73—83	Same	7,2	—	21,7	0,04
	C	95—115	"	7,4	—	18,6	Trace

Note: Comma represents decimal point.

Table 2 continued

Soil	Genetic horizon	Depth, cm	Texture	pH KCl	Total humus %	Total boron	
						In mg/kg	
Lowered medium thick peat. Woody-reed-sedge peat. Elgava region	T ₁	0-15	Peat, 60% decomposed	5,4	—	7,7	0,3
		15-30		5,6	—	6,2	0,5
	T ₂	30-40	Peat 50% decomposed	5,8	—	6,2	0,5
	T ₃	60-70	Peat, 40%-50% decomposed	5,8	—	4,6	0,7
		80-90		5,8	—	6,2	0,7
Cultivated lowland peat (peaty-gleyey). Elgava region	T ₁	0,19	Peat	5,3	—	—	0,20
	T ₂	19-28	"	5,8	—	6,2	0,16
	C	30-40	Gray sand	6,1	—	10,8	0,03
Upland peat, cotton grass-sphagnum peat. Elgava region	T ₁	0-10	Sphagnum, 3%-12% decomposed	4,0	—	Traces	
		10-17		4,2	—	"	"
		17-47		4,0	—	"	"
	T ₂	47-68	Sphagnum	4,0	—	3,1	"
	T ₃	80-90		4,0	—	3,1	"
	C	100-110	Sand	4,0	—	4,6	"
Peaty-gleyey on sand. Elgava region	A ₀	0-4	Peat	4,0	72,4	6,2	0,32
	A ₀	4-20	Same	4,5	64,0	4,6	0,25
	A ₁	21-31	Humified sand	5,1	8,2	6,2	0,04
	BC	33-43	Sand	6,0	—	12,4	Trace
	C ₁	60-70	Same	7,0	—	10,8	"
	C ₂	105-115	"	7,5	—	4,6	"
Transitional peat of medium thickness. Elgava region	T ₁	0-15	Sphagnum	4,0	—	—	—
	T ₂	15-20	Green moss	4,0	—	4,6	0,3
		20-30	Hypnum	4,0	—	3,1	0,3
		40-50	Reed-sedge	4,0	—	3,1	0,2
		80-90		5,4	—	3,0	0,1
		90-100	Peatified sand	5,6	—	Traces	
Lowland peaty-gleyey on carbonate sand, cultivated. Ogre region	A _{plw}	0-22	Well-decomposed peat	6,0	—	10,8	0,4
	A ₁	25-32	Peat, 40%-60% decomposed	6,0	—	10,8	0,4
	A ₂	48-58	decomposed	5,8	—	10,8	0,02
	B ₁	70-80	Sand	7,0	—	—	0,02
	B ₂	95-105	Sand with lime	7,5	—	7,7	Trace
	C	130-140	and gravel	7,5	—	7,7	"

Note: Comma represents decimal point.

BORON AND MOLYBDENUM

Scheme 1

Factors affecting the mobility and availability of soil boron to plants

Factors increasing the mobility of boron in soil and its availability to plants	Factors reducing the mobility of boron and its availability to plants
Addition of organic fertilizers and physiologically acid mineral fertilizers	Liming of acid podzolic soils in increased amounts, leading to the formation of complex compounds with sesquioxides, unavailable to plants
Mineralization of organic substances (plant remains, microbes, etc.), containing boron	Fixation of boron in the body of macro- and microorganisms and the formation of organic boron compounds
Lowering of the high concentrations of calcium in the nutrient medium. Increasing the intensity of the formation of acid root secretions of plants	Increase in the concentration of calcium ions in the soil solution, leading to unfavorable ratios of Ca and B in the soil solution

Table 3

Mo content in various soil groups of Latvia SSR^a

Soil	Molybdenum content			Average	% mobile Mo of its total content in soils	Correlation coefficient between mobile and total molybdenum
	Total, mg/kg	Average	Mobile, mg/kg			
I. Sod-podzolic and sod-gleyey unsaturated soils	0,25—1,1	0,58	Trace—0,27	0,08	6—20 (mean 10)	r = 0,580
a) Sod-podzolic sandy on marine sand	0,25—0,6	0,40	Trace—0,06	0,03	6	—
II. Sod-carbonate and sod-gleyey saturated soils	0,46—2,0	0,8	0,02—0,25	0,10	10	r = 0,855
Peat soils					5—100	
a) lowland peat	0,44—7,5	1,0	0,02—1,3	0,20	(mean 20)	r = 0,926
b) upland peat and transitional	0,13—0,78	0,4	Trace—0,04	0,02	5	—

^aThe analyses were made by N. N. Ivanova and L. V. Karelina.

Note: Comma represents decimal point.

formation the molybdenum may be removed from the upper soil horizons and fixed in the B horizon. The parent materials of podzolic soils have little mobile molybdenum. Molybdenum is more evenly distributed in genetic horizons of sod-carbonate soil, but here also the parent material contains less molybdenum, as a rule.

Water-soluble and adsorbed molybdenum is available to plants. But there is little of these forms of molybdenum in acid podzolic soils. This is true, first of all, of water-

soluble molybdenum. Adsorbed molybdenum is represented in soils primarily by MoO_4^{4-} which are adsorbed by clay minerals and are replaced by other anions, including oxalate and phosphate anions. Forms of Mo in soil which are available to plants may be judged to a certain degree by the amount of molybdenum going into salt solutions of oxalic acid, acetic acid, and phosphoric acid.

The availability of soil molybdenum also depends on the acidity of the soil and its phosphate regime. The availability of soil molyb-

Table 4

Distribution of molybdenum in genetic horizons of soils of Latvian SSR^a

Soil	Genetic horizon	Depth, cm	pH KCl	Total humus, %	Total Mo	Mobile Mo
					in mg/kg	
Sod moderately podzolized coarse clay loam on boulder clay loam. Plowed field. Dagda region	A ₁	0—15	4,9	1,9	0,53	0,08
	A ₂	20—30	4,6	0,3	0,40	0,07
	A ₂ B	38—48	4,6	0,3	0,66	0,08
	B	60—70	4,6	0,2	1,73	0,10
	BC	90—100	4,9	0,2	0,37	0,06
	C	115—125	7,7	0,1	0,40	0,02
Sod-podzolic-gleyey clay on boulderless clay. Meadow. Livan region	A ₁	2—13	4,1	7,8	0,70	0,08
	A ₂ B	15—20	4,1	1,8	0,76	0,11
	B ₂	25—35	5,0	1,0	0,83	0,13
	BC	50—60	5,9	0,6	0,63	0,11
	C	80—90	7,2	0,5	0,50	0,03
Sod-gleyey on a two-layered deposit, sandy loam on sand. Meadow. Livan region	A ₁	1—13	4,6	8,9	0,53	0,04
	A ₂	14—24	4,2	1,8	0,48	0,02
	B	25—30	4,3	1,8	0,60	0,03
	C	70—80	4,2	0,3	0,42	Traces
Strongly podzolized illuvial-humus peaty sands. Forest. Ogre region	A ₀	0—5	3,7	32,0	0,44	0,05
	A ₁	5—13	3,9	10,0	0,36	0,04
	A ₂	18—28	4,1	1,8	0,20	
	B ₁	55—65	4,4	2,4	0,40	0,05
	BC	88—98	4,7	0,3	0,26	Traces
Sod-carbonate podzolized clay on boulderless clay. Forest. Dagda region	A ₁	1—12	4,4	5,7	1,5	0,21
	B ₁	14—22	4,5	1,4	0,9	0,17
	B ₂	30—40	5,6	0,2	0,8	0,09
	C	60—70	7,3	0,5	1,1	Traces
Sod-carbonate leached clay loam on boulderless carbonate clay. Bauska region, Profile 4	A ₁	12—24	6,2	4,5	0,75	—
	A ₁ B	28—38	6,2	1,8	1,56	—
	B ₁	45—55	6,6	0,5	1,13	—
	BC	73—83	7,2	0,2	0,73	—
Sod-carbonate typical clay loam on carbonate morainic clay. Ludzen region	A ₁	0—15	6,8	1,6	0,60	—
	C ₁	30—40	7,0	0,3	0,53	—
	C ₂	70—80	7,4	0,2	0,53	—

^aThe analyses were made by N. N. Ivanova

Note: Comma represents decimal point.

denum increases as soil acidity decreases and the amount of phosphorus fertilizers increases. Liming also promotes an increase in the mobility of soil molybdenum.

Molybdenum of soil humus is bound in the form of various organic compounds which were contained in plant residues and microbe cells. This form of molybdenum becomes available to plants only after the mineralization of organic substances. Humic acids, free of sesquioxides, do not bind molybdenum.

Molybdenum which is part of soil minerals is not readily available to plants. Amorphous hydrates of ferric and aluminum oxides adsorb the MoO₄--- and change it to a less available state. This is why molybdenum is in forms not readily available to plants in acid podzolic soils containing much Al and Fe. Molybdenum is easily leached from sandy soils having an insignificant anion adsorption capacity.

Factors affecting the mobility and availability of soil molybdenum to plants are given in Scheme 2.

BORON AND MOLYBDENUM

Scheme 2

Factors affecting the availability of soil Mo to plants

Factors increasing the mobility of Mo in the soil and its availability to plants	Factors reducing the mobility of Mo in the soil and its availability to plants
Increase in the concentration of anion in the soil solution: OH^-, PO_4^{---}, etc. Addition of CaO, $\text{Ca}(\text{OH})_2$ and CaCO_3 Addition of phosphorous fertilizers containing soluble PO_4^{---} Mineralization of organic substances	Increase in the concentration of hydrogen ions Enrichment of soils with $\text{Al}(\text{OH})_3$ and $\text{Fe}(\text{OH})_3$, presence of exchange Al, excess of Fe^{+++} and Mn^{++} Addition of acid forms of mineral fertilizers, without lime Fixation of molybdenum by acid forms of humus containing sesquioxides

The availability of soil molybdenum to plants may be increased in areas of its deficiency by appropriate agricultural practices, such as liming soils and applying phosphorous fertilizers. The acidification of soils and their enrichment in sesquioxides should be avoided in these areas.

Conclusions

1. The total content and available forms of boron and molybdenum in Latvian soils have been determined. The total content of boron in various soils varies from 1.5-35 mg/kg of soil and the content of water-soluble forms of boron, from 0.2-2.0 mg/kg. Sands and sandy loams contain less boron than clays and clay loams. Sod-carbonate soil and soils of low-land peats with well-decomposed neutral peat are comparatively well supplied with boron. Boron in such peats is highly mobile. The humus horizon is richer in boron, as a rule, than other horizons.

Factors determining the availability of soil boron to plants have been studied.

2. The total content of molybdenum in various mineral soils in Latvia varies most often between 0.25-2.0 mg Mo per 6 kg of soil. The least amount of molybdenum is contained in coarse-textured sod-podzolic and sod-gleyey soils of the matritime zone. Molybdenum is most soluble in neutral peat soils.

The highest amount of total and mobile molybdenum is contained in the humus and illuvial horizons of sod-podzolic soils.

The solubility, or mobility, of soil molybdenum increases with increasing saturation of mineral colloids and humic acids with calcium. Molybdenum in soil is bound primarily by sesquioxides (iron and aluminum).

The availability of soil molybdenum is determined to a great extent by the acidity of the soil and its phosphorous regime.

3. Certain general principles of the behavior of boron and molybdenum in soil have been established, especially their relation to sesquioxides (iron and aluminum). At the same time there are essential differences. For instance, if the rate of liming is increased, the availability of boron to plants decreases, while the content of available molybdenum increases in soils.

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PROBLEM OF THE GENESIS OF RELIEF AND SYRT DEPOSITS IN THE TRANS-VOLGA REGION

G. P. SURMACH

Since parent material is the immediate substrate on which soil forms, it is one of the most important factors of soil formation. This is why the determination of the genesis of soil-forming material is not only of theoretical value, but also of great practical importance. The most widely distributed soil-forming materials in European USSR are loess and loess-like clay loams and clays. The least studied among these materials, as far as their genesis is concerned, are syrt deposits of the Trans-Volga region.

The most complete description of syrt deposits was given by Neustruyev (14, 15), who considered them as being "a water deposit of the continental type." According to Neustruyev they were deposited in fresh-water lake and swamp basins of the Volga region by fluvioglacial waters derived from an area to the east of it. Syrt deposits were later studied by Savarenskiy (21, 22), Rozanov (20), Mazarovich (10), Nikolayev (16), Gerasimov (3), and other investigators. The stratigraphic dissection of syrt deposits has been elaborated and opinions were advanced on its genesis. On the basis of the literature, the following layers may be distinguished in the friable deposits of the Trans-Volga syrt regions, which differ in their appearance, lithology and partly their distribution (from the lowest layer up): a) subsyrt sands which are most widely distributed and are thickest near river valleys; b) red-brown clays (red-brown and brown clays of various shades according to Savarenskiy [21]); and c) light-brown and yellow-brown clays. In addition, Gerasimov (3) distinguishes "intersyrt" deposits among red-brown and yellow-brown deposits, which are sandy-clay formations of uneven color and texture and often are found in the form of lenses. It must, however, be noted that Moskvitin, in his recently issued monograph (13), tries to represent syrt as a more or less homogeneous deposit of a similar geological age pertaining to the Upper Akchagyl, with which one cannot agree.

The total thickness of syrt clays reaches 50-60 m (14). The following hypotheses were advanced on the formation of various elements of syrt deposits: fluvioglacial (Neustruyev, Savarenskiy, Mazarovich, Gerasimov), lake-bog, or lake-lagoon (Neustruyev, Rozanov, Nikolayev, Gerasimov), and eolian, as far as the yellow-brown clays are concerned

(Nikolayev). In addition, Savarenskiy believed that part of the syrt clays formed from deluvial products of weathering of the Obshchiy Syrt. Let us note that ideas on the mode and conditions of syrt clay formation were expressed in general terms, without relation to the genesis of the relief of the syrt area. The various views on the genesis and time of formation of syrt deposits may be explained by the great complexity of the problem and the fact that the elements of syrt deposits and conditions of their occurrence have not yet been sufficiently studied.

Let us examine data on the characteristics of the flora and fauna of syrt deposits and of the so-called subsyrt sands. Sand deposits underlying the clay layer contain fresh-water fauna, a fact that was noted by many investigators (11, 14, 15, 16). The clay layer is very poor in fossil remains. According to Neustruyev, charred plant remains are sometimes found in syrt deposits, as well as the remains of mollusk shells, which, however, do not allow the determination of the age and conditions of formation of these materials because these fragments might have gotten there as a result of the reworking of older sedimentary materials. This fact was noticed earlier by Pavlov, when he described deluvium. As far as fossil animal remains are concerned, they were never found in syrt deposits beyond valleys (14, 6). According to data of Teryayev (24), the skeleton of an *Elasmotherium* was found in 1938 at the confluence of the Greater Karamana and Nakhoya Rivers. The skeleton was found in a buried humus layer on syrt clay which was covered with lake and river deposits containing fauna and flora. This discovery is an evidence of the Lower Quaternary age of this part of the syrt deposit. Recently Chernysheva (25) found the bone remains of a small rodent (marmot) in cinnamon-brown to brown clay near the village of Domashkiy Vershiny. She notes that "the species of the animal cannot yet be accurately determined." In spite of this, Chernysheva states that "this discovery allows one to conclude rather definitely at the present time that the cinnamon-brown to brown syrt clays and clay loams are of Upper Quaternary age." We do not agree with this. This discovery rather indicates that the syrt clays are of deluvial-proluvial origin.

A very important fact, in our opinion, is the

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vidence of ancient soil formation and remains a humus horizon in various parts of the Quaternary deposits. Evidence of soil formation was found in the upper part of subsyrt sands at the boundary with red-brown clays, on the surface of the red-brown layer, and in "intersyrt" deposits (14, 21, 3). It points to a change in the conditions of the medium toward favorable conditions for soil formation.

Pollen analyses of syrt clays did not reveal the presence of plant pollens in certain cases (personal communication of V. P. Voronichuk, who analyzed samples taken near Domashkiny Verkhiny), while in other cases pollens were found, especially in buried soil horizons (5, 25). This also points to the scantiness and, in certain cases, the absence of vegetation at the time of the formation of syrt deposits.

According to the most recent investigations (4, 10, 11, 13, 14, 15, 16, 20, 21, 22), syrt deposits in the depressions of ancient relief are underlain by blue, light blue, and grayish-greenish Akchagyl marine clays, which in their turn are found on primarily sandy Kinel' deposits. Mazarovich (11), who investigated the Kinel' horizon, believes that these are some sort of lake, river, or maybe, deluvial deposits."

Let us describe the characteristics of the relief and certain data obtained in our investigations on the profile of Quaternary deposits. As is known, a large part of the wide Trans-Volga syrt region, adjoining the Obshchii Syrt to the east, sharply drops in the west toward the Volga River valley and in the south toward the Caspian lowland (7). It is dissected by the valleys of the Samarka, Chapayevka, Chagra, Lesser Irgiza, Greater Irgiza, Greater Karasana, Yeruslan, and Greater and Lesser Uzeney Rivers, which are generally oriented to the west, southwest, and south and empty into the Volga River (except for the Uzeney River). Many tributaries of these rivers (small rivers) with intermittent stretches and large ravines (gullies) dissect the northern and southern slopes of the interfluvies. The heads of some of them became so deeply entrenched in the watersheds of the interfluvies that they lowered their height at corresponding points, especially where oppositely oriented summits are aligned. As a result of this, more or less pronounced saddles formed on the watersheds, which divide them into a series of syrts descending toward the Volga River.

It is important to note that the bedrock surface of the area described, in which sediments of all geological systems from the Paleozoic to the Tertiary (11) are represented, is a highly dissected piedmont valley relative to the Obshchii Syrt and Sokol'i Mountains, having a general slope toward the Volga River and the Caspian lowland. Having been covered later by friable deposits, this plain retained its subordinate hypsometric position as compared to the described points. Thus, the syrt slope, formed by a surface clay layer, gradually passing from the west to the east, passes over the dissected area of the Obshchii Syrt (and the Sokol'i Mountains to the north), which is free of surface deposits in its highest points.

Gravelly soils, primarily of the chernozem and chestnut groups, are usually found here to a lesser or greater degree. The syrt slope is dissected by the drainage network and slopes of second degree (toward river valleys), third degree (toward small rivers and ravines), and of other degrees form here. The asymmetry of watersheds in the interfluvies and between ravines is very pronounced in the Trans-Volga syrt region. Slopes exposed to the north, northeast, east, and northwest have acquired a greater length during their development and are more gentle than the opposite slopes. This is why their surfaces are much more dissected by troughs at intervals of 70-200 m from each other ("corrugation" of the surface).

We noted previously that yellowish, stratified "subsyrt sands" are found in depressions formed as a result of the intense erosion of Akchagyl clays, or in depressions of the bedrock relief. Their upper limit in the northern part of the syrt region is found between the 70-80 m contour, absolute elevation. Reaching a great thickness near river valleys (their visible thickness in the Volga zone of the Bezenchuk River basins is about 25 m, for instance), they rapidly thin out toward watersheds and wedge out. This is why they do not underlie the series of clay deposits everywhere. For instance, these sands are absent in the Samara-Chapayevka watersheds and its southern and western slopes (Chapayevsk area) and the layer of red-brown clay rests on the bedrock. Discontinuous sand deposits are also found on the left bank of the Komashka River (Fig. 1), in the left-bank depression of the Kinel' River (Fig. 2), and also in the lower reaches of the Tutuluka, and Sarbaya Rivers, and other points, where they only occupy the depressions in the bedrock relief, or Akchagyl deposits. In certain places the sands are underlain by gravel (exposed near Belovka on the Kutuluka River). The sands are horizontally and, sometimes, obliquely stratified. Fresh-water (and also reworked marine) mollusks found in the deposits at various points of the Trans-Volga region may be used to judge the age of these deposits.

We found the following forms:¹ *Cardium seudoedule* (Andrus), *Macra ossoskovi* (Andrus) (reworked Akchagyl), *Unio* sp. (Fragm), *Viviparus off volgensis* (Pavl.), *V. off. sinzovi* (Pavl.), *Bythinia* sp., *Pisidium* sp. *Lithoglyphus* sp., *Valvata piscinalis* (Mull) in the Lopatino ravine (Volga district) and *Unio ex gr. pietorum* (L.), *Viviparus off volgensis* (Pavl.), *Viviparus off sinzovi* (Pavl.), *Lithoglyphus naticoides* (Fer) in gullies, dissecting the slope in the area of Domashkiny Vershiny (the upper reaches of the Domashka River). A. G. Eberzin believes that the foregoing fauna complex, which characterizes the regime of flowing waters, may be synchronized with the upper portion of the Apsheron and the lower portion of the Baku stages.

It must be assumed that the series of sand deposits formed as a result of the presence of a river network abounding in water during the

¹The fossil molluscs were determined by A. G. Eberzin.

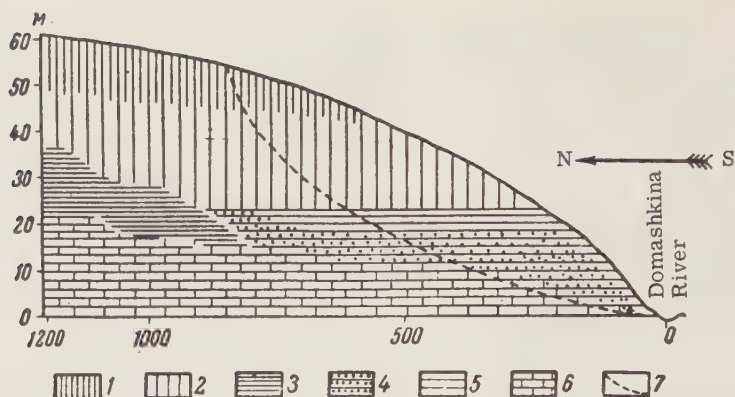


Fig. 1. - Schematic profile of the slope toward the Domashka River in the area of Domashkiny Vershiny

1 - yellow-brown clay; 2 - red-brown clay; 3 - dark bluish-light blue clay with fresh-water molluscs; 4 - yellowish stratified sand; 5 - Akchagyl' clay; 6 - red-colored original rock (Permian); 7 - outline of the bottom of the gulch.

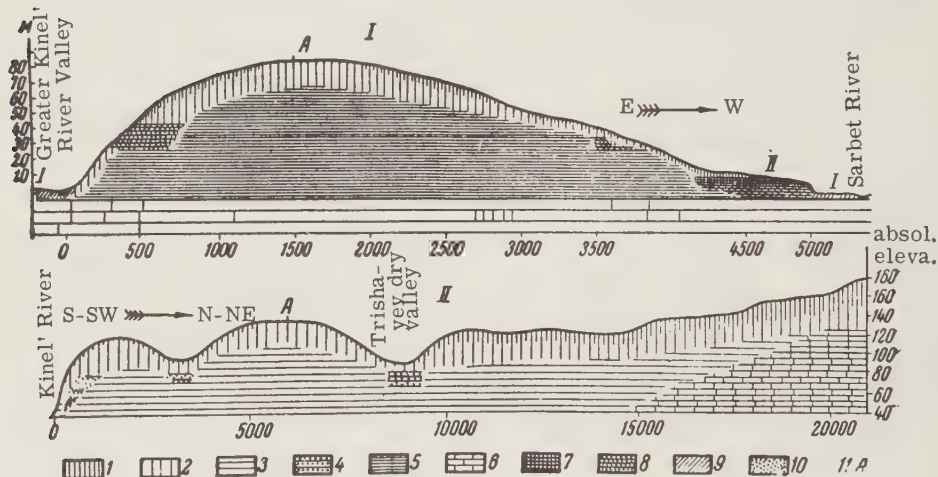


Fig. 2. - I - Transverse profile of the Kinel'-Sorabay watershed. II - Longitudinal profile of the same watershed.

1 - yellow-brown clay; 2 - red-brown clay; 3 - dark bluish-light blue clay with fresh-water molluscs; 4 - yellowish sand; 5 - Akchagyl' clay; 6 - original rock (Permian); 7 - brown sandy loam and clay loam of the second terrace; 8 - sandy deposits of the second terrace; 9 - pinkish-brown clay loam and clays of the first terrace; 10 - sandy deposits at the base of the first terrace; 11 - junction between the transverse and longitudinal profiles.

period of the melting of glaciers and snow is actually an old buried river terrace which we consider, along with Mazarovich and other investigators, to be the third flood-plain depositional terrace (probably Mindel).

As was mentioned previously, red-brown clays are widely distributed in the Trans-Volga region. They are found partly on sand deposits of the third terrace, but mostly on upper slopes and cover Akchagyl' clays and the bedrock (primarily red Permian marls and clays). They are one of the constant members composing

the watersheds of interfluvies, not only south of the Samarka River valley, but also of a large part of the area north of it. They compose the watershed depressions of the Kinel'-Kutulu and Kinel'-Sarabaya Rivers and also fill old erosional depressions in Permian deposits on the southern slope of the Sokol'i Mountains. The red-brown layer is a very compact material, abounding in lime concretions varying from several centimeters and up to 20-30 cm in diameter, and also in lime efflorescences and spots. However, in the immediate vicinity of river valleys (Spiridonov Profile), the lower

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naturally red-brown part of the layer contains almost no concretions. The presence of concretions and, in certain cases, that of buried soil horizons (Privet quarry in the Krotovka area) indicates that soil formation processes accompanied their formation. The layer is more intensely humified and has a cinnamon-brown to brown tinge in its upper part. According to our data, the humus content here reaches 5%-0.6% against 0.2% in the lower-lying, naturally red-brown part of the layer (the samples were taken in the exposed areas near Domashkiny Vershiny and in the Privet quarry near Krotovka). At the same time, the texture of both members of the Domashkin Profile is represented by clay and both are almost identical (Table 1), while in the Spiridonov Profile the red-brown material has a pronounced stratification and is texturally like a fine clay loam.

The upper, less red part of the clay layer is called by Savarenskiy "brown and cinnamon-brown to brown clay varying in shades." However, taking into account the similarity in the outward appearance, lithology and distribution of red-brown and cinnamon-brown to brown strata of the clay layer, one may assume that they are a single genetic formation. This is why we will consider as Gerasimov did, that both these strata represent a single clay layer, noting that its upper part formed in the presence of a comparatively richer vegetation.

It is very important to note that the highest points of certain syrts are not covered with yellow-brown clay, and compacted red-brown clay, being the soil-forming parent material crops out at the surface. The Kinel'-Sarbay watershed in the Timashevo region may serve as an example of this (Fig. 2). At the same time, other adjacent watersheds are covered with a layer of yellow-brown clay. We will consider this important fact when we examine below the mode of formation of the yellow-brown syrt layer. It must also be emphasized that the surface of the red-brown layer is strongly eroded, whereby at the time erosion is taking place cols formed locally on the water sheds, isolating individual syrt areas.

The yellow-brown loess-like clay layer, resting on red-brown clay, is found almost everywhere on syrt watersheds and gentle slopes

south of the Samarka River valley. Let us especially note that typical yellow-brown clays are also found on certain watersheds north of the Samarka River valley, even though they have a pinkish tinge, which can probably be explained by the wide distribution of red materials which served as the material for their formation. On southern and western slopes, yellow-brown clays often wedge out, exposing the underlying material down to the bedrock. Yellow-brown loess-like clays have many features in common with loess-like clay loams of the central parts of the Union, both as far as their outward appearance, distribution, and texture are concerned (Table 2).

Table 2 shows that the yellow-brown clays of syrts are distinguished by their high carbonate content and have a clayey texture, whereby clay and coarse silt particles predominate. The texture of loess-like deposits of the Central and Southern forest steppe (Central Russian Plain) is heterogeneous; here medium and fine clay loams and clays occur. This can be explained by the proximity of commanding heights consisting of various bedrocks, which at one time produced the material for the formation of these deposits. The farther a given point is located from the commanding heights, the more homogeneous the surface deposits on it become.

Let us examine the question of the genesis of syrt deposits. As far as the so-called "subsyrt sands" are concerned, it was already mentioned that they represent flowing water deposits and may be considered as a depositional terrace. A geomorphological analysis shows that this is nothing else than the third flood-plain terrace, mostly buried by subsequent deposits. The sands occupy the base of the terrace, while sandy loams and clay loams of varying colors cover them. Taking into account the large area of the terrace, it must be assumed that its lower part formed as a result of the erosional-depositional action of a tremendous amount of glacier water draining into large river beds probably during the Mindel epoch.

We have already mentioned at the beginning of the article that various hypotheses were advanced on the origin of red-brown and yellow-brown clays, such as the fluvio-glacial, lake-lagoon, eolian, and partly deluvial. According

Table 1

Particle-size composition of the red-brown clay of the Trans-Volga region in percent

Location	Clay and depth, cm	Loss on treatment with 0.05-N HCl	Particle diameters, mm						
			1.0—0.25	0.25—0.05	0.05—0.01	0.01—0.005	0.005—0.001	<0.001	<0.01
Domashkiny Vershiny area	Red-brown, 8	11,09	0,33	2,46	20,41	9,05	12,65	44,01	65,71
Same									
Spiridonovka area	Cinnamon-brown	14,13	0,74	0,93	17,44	8,85	11,16	46,75	66,76
	Red-brown, stratified	12,65	0,56	16,46	16,93	5,75	12,26	35,39	53,40

Note: Comma represents decimal point.

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to the fluvioglacial hypothesis, syrt clays (yellow-brown) were deposited under conditions of the complete flooding of water divides by glacier water when they were dammed by the waters of the Caspian transgression. Such damming could have occurred only in the presence of a single basin, similar to the Akchagyl basin, but larger. But in this case, syrt deposits should have contained marine fauna and have belonged to marine deposits, which is not substantiated by available data (14). The known facts about the distribution of syrt clays on high watersheds (up to 180 m absolute height and higher) and their absence on neighboring, much lower watersheds also disagree with this hypothesis. The same facts also do not agree with the eolian hypothesis of the formation of yellow-brown clays. By assuming that syrt clays are of fluvioglacial origin, we must deny the relation between the first and second flood-plain terraces and glacier waters. Further, the absence of yellow-brown clay in certain areas of flat watersheds (red-brown clay crops out at the surface) and its presence in neighboring watersheds also do not agree either with the fluvioglacial or eolian hypotheses. The eolian hypothesis was strongly criticized by Berg (1).

As far as the assumption of the sedimentation of clays in stagnant basins is concerned, the continuous distribution of such basins on watersheds and slopes in dissected relief is not possible. In addition, the idea of the existence of lakes, or the partial water-logging of the area, does not contribute to the solution of the problem, or does not exclude the possibility of a deluvial process and the existence of an area being destroyed from which fine earth material may have been derived. The fluvioglacial and, especially, the lake-lagoon hypotheses do not agree on the one hand with the absence of fresh-water mollusks and peat in the series of clay deposits and, on the other hand, with the clear evidence of soil formation and the presence of animal remains in it (24, 25).

Thus, the foregoing hypotheses do not satisfactorily explain the genesis of syrt clays and the more so the genesis of the relief. We believe that the origin of these clays may be understood only from the point of view of the deluvial-proluvial theory of Pavlov (17, 18), and the concept of Kozmenko (8), which consider the genesis of the relief and surface deposits as one process developing under the influence of climatic and related biological factors. Makkaveyev (12) attributes a great role to climatic conditions in the formation of river beds and river terraces.

Climate is the most important factor in runoff formation and determines the degree to which vegetation covers the surface in various epochs. It is important to note that in dry, cold epochs, the scantiness of vegetation led to intense slope erosion and the removal of fine earth, which accumulated in the plains.

As far as the genesis of syrt clays is concerned, we must note that the arguments given below in favor of the deluvial-proluvial theory are based on a lesser amount of material and are less conclusive with respect to the red-brown layer than they are with respect to the yellow-brown layer. Nevertheless the theory

seems convincing to us. Let us remind you of the following facts: 1) with respect to the elevated areas of the Obshchiy Syrt and the Sokol'i Mountains the syrt area is a piedmont valley into which large amounts of fine earth, derived from the destruction of these mountains, could not have been discharged; 2) the red-brown, as well as the yellow-brown loess-lake layer, does not contain fresh-water mollusks (except for their reworked fragments), which would have indicated that it was deposited in a stable water medium; 3) the red-brown layer contains a large amount of lime concretions as well as a considerable amount of humus and even buried humus horizons, which is an indication of soil formation processes and of its deluvial-proluvial origin.

We think that the formation of red-brown clay took place in the following manner. After the glaciers had melted and had deposited a thick layer of sand material (third terrace — "subsyrt sands, "), an interglacial epoch followed with a dry and probably cold climate. During this epoch red-brown clays formed as deluvial-proluvial deposits transported by overloaded streams from the slopes of the Obshchiy Syrt and the Sokol'i Mountains, as well as the slopes of local elevations (consisting of bedrock and Akchagyl materials) into the piedmont valley, filling relief depressions and the slopes. This process was very intense because of the weak development of soil owing to scant vegetation, which is evidenced by the weak humification of these deposits. The loaded waters carried part of this material into the valleys where it partially settled as alluvium (during the following erosion epoch, most of the alluvial particles were removed from red-brown clay). The formation of deluvium-proluvium becomes clearer when one takes into account that in the absence of soil, or when it is weakly developed, the most insignificant runoff may lead to the intense transport of fine earth along small streams; in addition, the most scant precipitation or meltwater may cause surface runoff as a result of the very low absorption capacity of undeveloped clay soil, or material. Such a picture may be observed at present in fresh depressions, where the syrt layer is bare of soil. With normally developed soil, the formation of such deposits under virgin conditions is impossible, because erosion does not take place on well-sodded slopes. This principle, which is quite clear to investigators studying contemporary erosion processes, is usually not sufficiently considered by geologists and geomorphologists. In relation to this, let us remind you of the words of P. A. Kostychev: "Maybe all those who attributed a great importance to erosion and the removal of humus were misled by observations primarily in plowed areas." "I had occasion to travel thousands of versts over areas of unplowed chernozem and could find neither erosion nor any sign of it, no matter how I tried" (9). This point of view is substantiated by experience gained over a long period of time at the Novosil'sk Experiment Station and also by our experimental data.

Toward the end of the interglacial epoch the climate apparently changed and became more humid and this led to the intensification of the soil-formation process, which is evidenced by the increase in the amount of humus in the upper

part of the layer and the presence of buried soils in certain cases. The formation of soil led to a decrease in slope erosion, which, in its turn, led to a sharp decrease of the turbidity of surface runoff and promoted the cutting of the river network into the loose deposits proper. The erosion level lowered as a result; this was probably also related to the eustatic lowering of the level of the Caspian basin (as a result of excess evaporation from its surface over the inflow of water) and, maybe, the lowering of its bottom (2, 19).

Later, an increase in runoff occurred again, which was possibly related to the melting of accumulated snow during the Riss glaciation of neighboring regions more to the north. This led to the destruction of soil and strong erosion of the surface of the red-brown layer. The heads of the ravines began to cut into watersheds, dissecting them into syrts. Separate syrt areas in the border zone of the eastern and northern part of the area became isolated from the above-lying surface, which stopped the supply of fine earth material to them. During this epoch of erosion, coarser sandy and clay loam deposits formed on slopes, which were designed by Gerasimov (3) as "intersyrt" deposits. Such deposits, which are represented by brownish stratified sands with reddish grains (which indicates their genetic relation with red-brown material), are found on the Kinel'-Sarbay watershed in the area of Timashevo. This erosion cycle manifested itself in valleys in the strong erosion of loose deposits of the preceding glacial and interglacial epoch, the deepening and widening of river beds and the formation of the ledge on the third flood-plain terrace; during this erosion process, gravelly and sandy deposits formed at the base of the second terrace.

After the snow and glacier waters ran off, the climate became dry and probably cold again and unfavorable to vegetation. Under such conditions silty yellow-brown loess-like clays formed deluvially. In order to prove this point, let us refer to the previously mentioned absence of yellow-brown clay on the elevated portion of the Kinel'-Sarbay watershed (130 m absolute elevation), which was isolated during the preceding period of erosion, while it is present in the more elevated neighboring area. This fact points out, on the one hand, that the eolian and fluvioglacial hypotheses are unfounded and, on the other hand, substantiates the deluvial origin of yellow-brown clays. The presence of yellow-brown clay on gentle slopes of the Kinel'-Sarbay watershed indicates that they formed from the deluvial reworking of red-brown clay. From this it is clear that the material for the formation of yellow-brown clays could have been supplied not only from mountain ridges (Obshchiy Syrt, Sokol'i Mountains), but also from higher areas consisting of red-brown clays. Deluvium elongated the gentle slopes, filled depressions and descended into the valleys (during floods). Thus, deluvial deposits and flat alluvial plains formed simultaneously in the valleys, which later became the second flood-plain terrace (coarser sandy-clay material was deposited in the Volga River valley, because of its abundance in water). This was an unusual deluvial desert which was being slowly colonized by vegetation, primarily because of unfavorable climatic conditions. During

this epoch, such animals as the mammoth, the woolly rhinoceros, etc. died because of the scant vegetation and a deficiency in forage.

With time, a more or less continuous vegetation formed as a result of its replacement and the soil-formation process intensified; this was probably promoted by climatic conditions. As a result of this, the deluvial process began to die out; it could have stopped completely provided the soil surface had been well sodded.

During the next epoch, a sharp increase in erosion occurred as a result of the runoff of snow and glacier waters related to the Würm glaciation, which left deep traces behind them in the form of a strongly eroded drainage network, the ledge of the second flood-plain terrace, the sandy foundation of the first terrace in river valleys, and the dissection of the syrt area. The ravine network grew toward the water-watersheds and the soil was destroyed and both yellow-brown and red-brown soils were eroded off the steeper southern slopes. All this led to the formation of pronounced cols and the isolation of separate watershed ridges. Thus, the isolation of certain syrt areas by water flowing from the general syrt slope could have occurred after the upper syrt layer had formed. During runoff on gentle slopes, as well as steeper slopes, new, derived deluvial syrt clays formed (primarily yellow-brown), which in many cases almost do not differ from the actual yellow-brown clays. In a trench cutting across slopes and the first flood-plain terrace in the Timashevo region, one may see the transition from the newest deluvium into the alluvial clay deposits of the first terrace, which had formed during the epoch which followed the maximum runoff of waters related to the last Würm glaciation.

It is interesting to note that the upper series of clay deposits on the first terrace of the Greater Kinel' River has a definite reddish tinge, which is not found in the deposits of the first terrace of southern rivers in the Trans-Volga region. This may probably serve as a sign of the genetic relation of the clay deposits of the terrace with red Permian marls, clays and their deluvial derivatives, found in this catchment system.

During the epoch immediately following the disappearance of glaciers in Northern Europe, vegetation gradually overtook the parent material as a result of the dryness of the climate. Later, the soil-formation process intensified, sod and forest litter developed, and slope erosion stopped. Erosional formations remained the same as they had developed then. Relief acquired its present outlines.

The following increase of erosion processes, related to a considerable wetness of the climate (it probably corresponds to the so-called Noe-würm epoch) left clear traces in the form of a washed out drainage network with normally-developed soil and, in certain cases, forest vegetation centuries old. The ledge of the first flood-plain terrace formed at this time in northern valleys (north of the Samarka River) and sandy-clayey, noticeably humified flood-plain deposits (in contrast to very weakly

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unified deposits of flood-plain terraces) began to form. The new flood plains of southern rivers in the Trans-Volga region were less sculptured than in the north, because of lesser runoff; here they have the form of narrow trough-like depressions which are able to hold maximum runoff during floods. A network of depressions formed at the same time on long syrt slopes, which make their surface corrugated and complicate erosion control in our times.

This, in general terms, is the genesis of the relief and syrt deposits of the Trans-Volga region.

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DISTRIBUTION OF DUST STORMS IN THE NORTHERN CAUCASUS AND AN EXPERIMENT ON THEIR CONTROL BY MEANS OF FOREST BELTS

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The agriculture of the steppe regions of the Soviet Union frequently suffers damage from dust, or black storms, during which seeds or young plants are blown off with the soil. The fine earth lifted by the wind may be transported over great distances, covering and damaging agricultural crops, roads, and various installations in its way. According to approximate calculations by Sus (11), an area of more than 31 million ha is subjected to wind erosion in the Soviet Union.

Dust storms are very frequent in the Northern Caucasus. In the last 10 years, dust storms occurred in the Northern Caucasus almost annually. Severe storms took place in the northern regions of Krasnodar Province in 1951 and 1952. According to data of Karayevov (5), chief agronomist of the Stalin Sugar Beet Combine (Novokubansk village), dust storms damaged agricultural plantings five times from 1949-1957. The area covered by the destroyed plantings averaged 5% of the total planted area of the combine.

Because of the virgin and abandoned lands (of a coarse texture) adjoining the Terek-Kum desert, without using anti-erosion measures, deflation became an annual occurrence. According to the data of Gayel (2), more than 11000 of sowed fields were lost in the Shelkov district, Groznensk Oblast', from 1950-1954. The mean yield of grain crops on eroded soils was only 1.5 ctnr/ha. About the same picture was observed in other areas of the Groznensk Oblast'.

In the spring of 1957 dust storms damaged agricultural crops over an area of 120,000 ha in the southern part of the Rostov Oblast' (from the Don River to the southern boundary of the region) and over more than 300,000 ha in Stavropol' Province. In the Rostov Oblast' 3.4% of the total area under grain crops was completely ruined.

Especially severe storms occurred in the spring of 1960 in the Northern Caucasus. In March and April of this year an area of about 400,000 ha was damaged by wind erosion in the Rostov Oblast' alone. But the most important negative consequences of dust storms are not only the direct losses, but primarily the loss of soil productivity as a result of the deflation of the upper, most fertile humus layer of the soil.

The study of the frequency and distribution of storms is of great importance to the development of crop rotation and the planning of organizational-economic and agricultural forest melioration measures. To determine the areas most susceptible to the action of dust storms we used data from 20-year records at 4 meteorological stations and 5-year observations at 25 meteorological stations located in the Northern Caucasus,¹ as well as information from questionnaires sent to agricultural institutions, sovkhos administrations, and other organizations.²

The material and information collected on dust storms embrace an area extending from the Don River to the south to the Caucasus and from the Black Sea to the Caspian Sea. The large amount of material available permitted us to establish the principles governing the distribution and frequency of dust storms in the region studied.

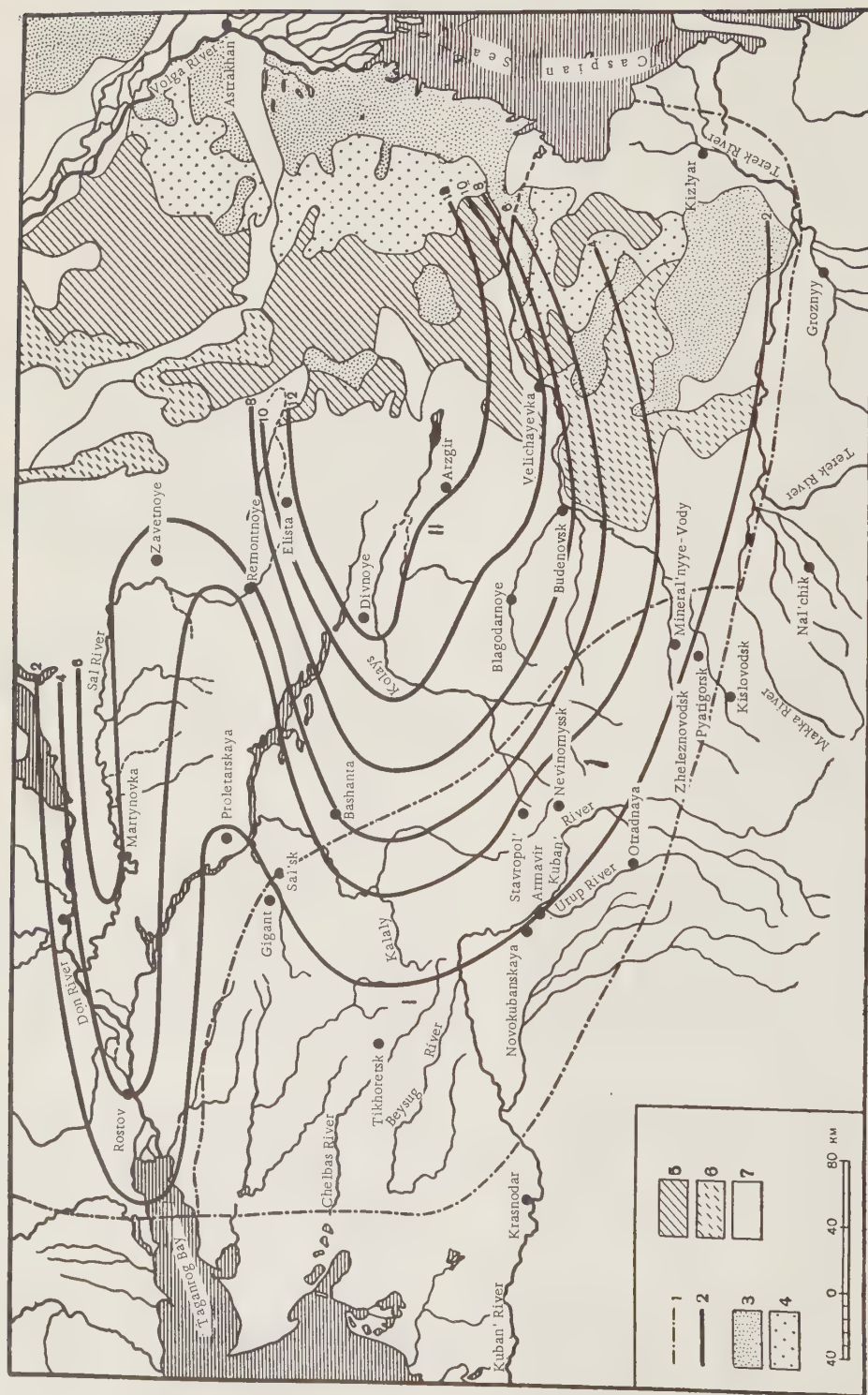
After having determined the mean annual number of dust storms for each meteorological station, we plotted the data obtained on a map and then connected the points with the same number of dust storms by isolines.

The map clearly showed the zone of maximum storm development, embracing the Elista, Divnoye, and Velichayevka regions (see map). Here storms occur with a mean frequency of 10 to 12 times a year, while in individual years (especially dry years and years with dry winds) the number of storms reaches 48 to 50.

Even though all the available material for the area to the northeast of the zone of maximum dust storms was used, it was not sufficient to determine the northeastern boundary of this zone and this is why no isolines were plotted here. The number of storms decreases considerably from the region of the maximum to

¹ Meteorological stations have recorded phenomena (dust storms) during which there is a large amount of dust or sand in the air, lifted by strong winds, since 1936.

² In addition we used certain data collected by K. P. Boyarchuk, made kindly available to us.



Schematic map of the distribution of dust storm in the Northern Caucasus

1 - boundaries of deflation areas; 2 - isolines of equal number of dust storms per year; 3 - sands; 4 - sandy soils; 5 - sandy loam; 6 - clay loam, primarily silty; 7 - clays and fine clay loams.

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the foothills. Thus 5 to 8 storms occur in 10 years at the meteorological stations of Kislovodsk, Zheleznovodsk, and Novo-Pyatigorsk. The number of storms also decreases to the west, but less to the north of the Stavropol' plateau than to the southeast, apparently because of the shielding influence of the Stavropol' plateau against easterly winds. The influence of relief on the distribution of dust storms also manifests itself in other areas of the region.

The number of dust storms per year is considerable in the region of the Salo-Manych steppes, in the northwest it reaches two and in the southeast, eight per year. A great number of dust storms occur in the Kumo-Manych lowland, passing through Arzgir, Divnoye, to Veselyy village, and in the southeastern part of the Salo-Manych ridge. Here, the increased dust storm frequency is promoted by the specific climatic conditions associated with deficient moisture, the long duration of rainless periods, considerable warming of the soil and air in July-August, and also strong winds. The frequency of dust storms decreases in the Salo-Manych plateau, and increases again in the region of the Don basin. The isolines here form a loop reaching far to the west.

The annual distribution of dust storms reveals two regions of maximum dust storm occurrence, falling in two different seasons. These are the deflation areas shown on the schematic map.

In the first region the storm maximum occurs in spring, in March-April and in the first half of May, and in the second, in July-August. The first deflation area includes the northern and central parts of Krasnodar Province, the southern part of the Rostov Oblast' (from the line Rostov-Bashanta to the south), and the eastern part of Stavropol' Province (along the line Bashanta-Stavropol'-Mineral'nyye Vody).

The second region includes the southern and southeastern parts of the Rostov Oblast' the western half of the Kalmyk ASSR, the eastern part of Stavropol' Province, and the northern part of the Checheno Ingush Republic.

Thus, all meteorological stations form two groups and are territorially united into two regions.

The first deflation area is characterized by the following climatic data. Annual precipitation amounts to 500-550 mm. The prevailing winds are easterly and westerly, whereby easterly winds occur in spring and autumn. The mean annual wind velocity does not exceed 2.4 m/sec. The strongest winds occur in February, March, and April, and the weakest, in June, July and August. In individual years easterly winds sometimes reach 20-25 m/sec velocity.

Dust storms in the first deflation area occur on the average 2 to 3 times a year. According to long-period data the maximum number of dust storms (57% of the cases) occurs during the windy spring months (March, April) when the plowed soil is not sufficiently covered with vegetation. The dust storm frequency decreases to 30% in summer and to 11% in autumn. Dust

storms are rare in winter (2%) and usually occur during years with low temperatures and shallow snow cover. In this respect 1951 was an interesting year when soil deflation was observed in winter in a number of areas of the Rostov Oblast'. In January-February of 1951 soil deflation occurred 21 times in the Novocherkassk district. Storms developed at wind velocities of 8-16 m/sec, mostly with easterly winds (75% of the cases), more rarely with westerly winds (20%), and very rarely with winds from other directions.

The comparatively small number of storms in this region may be explained firstly by a more mild climate (considerable moistening, and relatively low summer temperatures), as a result of which the soil here is very soddy, which in itself is a great obstacle to deflation, and, secondly, to the absence of strong winds in summer and autumn.

The second deflation area is characterized by an insignificant amount of precipitation, from 200 mm in the east to 400 mm in the west of the area, and prevailing easterly and north-easterly winds, which are dry in summer and very cold in winter. The mean annual wind velocity is about 5 m/sec. The number of dust storms in the region is great, especially in its central part. Storms occur here on an average of 10 to 20 a year. As mentioned earlier, the number of days with dust storms decreases to 2-4 a year in the southern and northwestern parts of the region. Dust storms occur in this region from February to November, however, the largest number occurs in summer, in July-August (58%) during the dry period which is characteristic for these areas and which lasts with minor interruptions to early October. The number of storms decreases to 27% in spring, to 13% in autumn, and to 2% in winter.

The frequent occurrence of dust storms may be explained by the fact that the general surface slope of the region is oriented to the east, against the dry easterly winds prevailing here, and by the fact that the greatest part of the region is occupied by sands and sandy soils which are very susceptible to deflation (see map), and by insignificant moisture (200-400 mm of precipitation a year), and the scant vegetation associated with it. Dust storms occur here most frequently, as in the first region, during winds from the east (50%-80% of the cases), somewhat more rarely during winds from the west, and very rarely during winds from other directions. Dust storms are most frequent at wind velocities from 6-10 m/sec (65%-75% of the cases), that is, less than in the first deflation area.

In both regions storms usually begin in the morning (9-11 a. m.), reach their maximum development toward noon, and die out toward the evening. Black storms are rare at night.

Wind erosion control may be achieved, as pointed out by Dzetovetskiy (4), Karsandov (6), Moiseyev and Vasil'chenko (8), and others, by a complex of meliorative measures oriented toward the protection of soil against destruction and deflation. This complex must include: 1) the proper organization of the area; 2) crop rotation corresponding to local conditions and

high-quality agricultural practices; and 3) the establishment of forest shelterbelts.

Forest shelterbelts, which reduce wind velocities, weaken deflation, improve the soil moisture, and promote the better growth and development of field crops, are of great importance in the protection of soil against deflation and crops against damage from wind erosion. Long-period observations showed that on farms where the fields are surrounded by forest shelterbelts, there is no deflation of soil and plantings. Thus, for instance, no damage to plantings by dust storms has been observed for a number of years in the Stalin kolkhoz and in the grain crop "Gigant" sovkhov in the Sal'sk district, Rostov Oblast'. Even during the extremely severe dust storms which occurred in March and April 1960, there was no damage to plantings here. There was no damage either in the "Leninets" kolkhoz in the Sal'sk district, in the Kirov kolkhoz in the Mechetinsk district, and in the Ist of May kolkhoz in the Tselinsk district, all of which have a system of forest shelterbelts. At the same time, the fields of neighboring kolkhozes, which do not have forest shelterbelts, suffered greatly from the dust storms in 1957 and 1960, especially the Chapayev and "Put' Pl'icha" kolkhozes. In these kolkhozes forest shelterbelts occupy a very small area, and are planted thinly and haphazardly. However, even in this case the fields which were protected by forest shelterbelts from the damaging winds did not suffer, or suffered less from the dust storms. In the "XX Party Meeting" kolkhoz in the Krasnosulinsk district, a field which was protected from the east by a forest shelterbelt 6 m high, winter crops were not damaged in a strip 400 m wide in 1960. In another field, also protected from the east by a forest shelterbelt 4.5 m high, plantings were not damaged in a strip 150 m wide. The same was observed on many other farms in the 1957 and 1960.

In fields surrounded by forest belts in the Stalin kolkhoz in Libknekht district, Stavropol' Province, the yield from one hectare was 6-9 cmt higher than in non-protected fields in a year with an especially high number of dust storms (1948). It was not only possible to save winter crop plantings, but also to obtain a high yield in the "Rodina" and "Kolos" kolkhozes of the Petrov district, Stavropol' Province, owing to shelterbelts, while in the Lenin kolkhoz in the same area, where fields were not protected by forest belts, plantings were blown away from an area of 4500 ha.

In this respect data given in Table 1 are very interesting, they show how the planting areas, subjected to dust storms, decreases in certain regions of Rostov Oblast' and Stavropol' Province, depending on the coverage with forest shelterbelts.

All the foregoing data convincingly show the effectiveness of forest belts in the control of soil deflation, especially if these belts form a definite system and are used in conjunction with other agronomical measures.

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Table 1

Damage to plantings by dust storms depending on the area of forest shelterbelts

Regions	Mean frequency of dust storms per year	Area occupied by forest shelterbelts in % of the plowed area		Damaged plantings in % of the total area planted
		Total	Including forest belts	
Yegorlyk, Rostov Oblast'	2	2,0	1,3	3,5
Tselinsk, Rostov Oblast'	2	2,2	1,7	2,3
Fedorov, Rostov Oblast'	4	1,2	0,2	1,3
M. Kurgan, Rosvo Oblast'	4	2,6	0,2	0,7
Stepnov, Kalmyk ASSR	7	0,2	0,1	3,3
Sal'sk, Rostov Oblast'	7	3,7	2,9	0,9
Krasnogvardeysk, Stavropol' Province	6	0,7	0,3	14,1
Arkhangel'skoye, Stavropol' Province	6	9,7	1,5	1,2

Note: Comma represents decimal point.

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MODIFICATION OF SOD-PODZOLIC SOILS UNDER MEADOW VEGETATION

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In considering soil formation as a combination of synthesis and decomposition processes, and the migration and accumulation of organic and mineral substances, V. R. Vil'yams believed that in the taiga zone podzol formation dies out and the sod process develops when forests are replaced by meadows (1). This conclusion has unfortunately not been sufficiently verified experimentally and has not been further developed to this day. On the basis of only a few investigations (6, 2, 3, 4), we may consider that the only fact established is that a thick humus horizon develops in sod-podzolic soils under dry valley grass vegetation, and that it is enriched in nutrients. However, the problem as to what degree the podzolic process dies out and the sod process develops, as well as that of the characteristic features of the latter in these soils, remains open.

The investigations conducted by us in the Kaliningrad,¹ Kalinin, and Kirov Oblasts' on a number of clay loam sod-podzolic soils under a spruce forest and under a natural dry-valley mixed-grass meadow 60-80 years old, located on flat, well-drained watersheds on homogeneous relief elements and similar (within individual areas) parent materials, allow certain conclusions on this problem.

1. The prolonged action of dry valley grass vegetation in well-drained watersheds on sod-podzolic soils does not lead to the accumulation of humus in them and does not change the nature of humus formation (Table 1).

In the composition of humus under grass vegetation humic acids increase slightly, but fulvic acids predominate, especially their free and mobile forms. The migration of fulvic acids toward the lower part of the profile is very pronounced both in soils under forest vegetation and soils under dry meadows. Only in the soil of the Kaliningrad Oblast' under the sowed perennial meadow does the amount of humic acids increase noticeably as compared with the soil in the forest and in the natural dry meadow, and among these acids those predominate which are more strongly bound with the

mineral part of the soil. This is determined by the history of the meadows which were formerly drained, limed, dressed with organic and mineral fertilizers, and systematically cultivated.

The study of the optical density of humic acids showed that under grass vegetation more favorable conditions are created for their accumulation, since in these soils the fractions of humic acids firmly bound with the mineral portion are characterized by a higher density than the same fractions extracted from the soil under the forest. However, this condensation process develops very slowly, the mobile forms of humic acid in the soil from the dry meadow are less dense than in the forest. The main reasons for such a trend in humus formation in sod-podzolic soils under meadow vegetation are the unfavorable water regime, insufficient saturation with calcium, and the paucity of colloids in the upper horizons. Periodic supersaturation and leaching to the bottom sharply slows the condensation of humic substances; they are easily subjected to mineralization and removal. Only the long-time use of a complex of agricultural practice and the systematic sowing of grasses lead to a considerable change in the nature of humus formation in the taiga zone.

2. Meadow vegetation has a much more significant effect on the biological accumulation of adsorbed cations (Table 2). The layer-by-layer determination of the amount of adsorbed cations showed that the degree of removal and accumulation differs depending on land use.

The most intense removal of Ca and Mg from the upper 0.5 m occurs in the soil of the forest (in the podzolic horizon removal reaches 70%-80%)². Here cations are replaced to a great extent by exchangeable aluminum, the presence of which may be considered as a sufficiently clear indication of the intensity of contemporary soil formation (decomposition of minerals). Under dry-valley grasses the removal of cations

¹In the Kaliningrad Oblast' we also investigated a sod-podzolic soil under a sowed perennial meadow.

²There is no removal of cations only in the uppermost humus horizon in the soil of the forest in the Kaliningrad Oblast', because of the intense biological accumulation as a result of the high ash content of plant litter.

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Table 1

Group and fractional composition of humus in sod-podzolic soils^a

Oblast'	Land use	Depth, cm	Hu- mus	N	C : N	Humic acids		Fulvic acids			Humic acids Fulvic acids	
								Total in % of humus	In % of their total content			
			In % of dry soil	Total in % of humus		Mobile in % of their total	Free		Mobile			
Kalinin	Conifer- ous forest	4—12	4,26	0,21	11,9	19	79	27	21	75	0,70	
		12—22	1,06	—	—	14	65	50	33	46	0,28	
		36—46	0,39	—	—	18	52	43	32	46	0,42	
	Dry-val- ley mea- dow	0—15	2,57	0,14	10,7	21	63	33	19	57	0,63	
		15—25	0,28	—	—	23	51	46	40	34	0,50	
		25—35	0,22	—	—	22	32	46	51	29	0,47	
Kalinin- grad	Conifer- ous forest	2—10	5,65	0,32	10,4	16	56	27	16	58	0,59	
		10—20	1,25	—	—	16	70	34	27	47	0,47	
		44—53	0,22	—	—	18	52	40	23	50	0,45	
	Dry-val- ley mea- dow	0—10	1,85	0,0	10,9	19	55	30	13	59	0,63	
		10—21	1,29	0,08	9,4	24	47	33	21	47	0,72	
		21—35	0,50	—	—	15	41	43	30	38	0,35	
		45—54	0,19	—	—	21	43	56	30	35	0,37	
	Sowed peren- nial mea- dow	0—10	2,33	0,15	9,0	21	45	27	20	55	0,78	
		10—20	1,45	0,10	8,2	30	39	31	18	50	0,97	
		20—27	1,29	—	—	30	38	31	22	41	0,97	
		27—36	0,64	—	—	9	38	36	30	30	0,25	
		50—64	0,28	—	—	13	9	57	13	36	0,23	
	Kirov	Conifer- ous for- est	3—10	4,42	0,21	12,1	13	69	37	22	54	0,35
			10—27	0,47	—	—	19	53	42	29	47	0,45
			37—51	0,44	—	—	25	64	35	42	29	0,71
Dry-val- ley mea- dow		0—14	2,61	0,17	9,1	24	38	29	14	41	0,83	
		14—26	0,51	—	—	25	40	38	50	21	0,66	
		47—55	0,31	—	—	22	54	41	32	32	0,54	

^aThe total amount of humic and fulvic acids was obtained by treating soils with a 0.1 N solution of NaOH after decalcifying it with a 0.1 N solution of H₂SO₄; mobile forms were obtained by direct treatment with a 0.1 N solution of NaOH; free fulvic acids, by treatment of soil with a 0.1 N solution of H₂SO₄.

Note: Comma represents decimal point.

is less intense both in the humus and in the podzolic horizons because of intense biological accumulation, and the Al content is very insignificant. The predominance of fulvic acids in the composition of humus, and the high solubility of Ca and Mg fulvates allow the conclusion that these cations probably migrate under grasses, but removal is compensated for to a great extent by the biological accumulation of these cations by the root systems of grasses in the lower horizons. Analyses of the grass root system showed that it is characterized by a high ash content, whereby the ash contains a large amount of calcium, magnesium, phosphorus, sulfur, silicon, and sesquioxides. These biogenic forms of Ca and Mg probably greatly neutralize the fulvic acids formed, which thus do not exert a pronounced podzolizing influence under grass vegetation. The pH of the water extract of all soils under meadow is close to neutral, while

the reaction of the water extract from the soil in the forest is acid.

The biological accumulation of adsorbed Ca and Mg is very pronounced in the entire upper 0.5 m layer of the soil profile in the sowed perennial meadow of Kaliningrad Oblast', as compared to the soil of the dry meadow, and their distribution is not typical of sod-podzolic soils. The amount of exchangeable Al is insignificant.

3. The prolonged action of dry valley grass vegetation on sod-podzolic soil exerts a noticeable influence on all major components of the aluminosilicate portion of the soil (Table 3). Its decomposition and removal are most pronounced in the forest soils. They embrace practically the entire soil profile down to the parent material. The decomposition and removal of aluminosilicates

Table 2

Composition of adsorbed cations in sod-podzolic soils

Oblast'	Land use	Depth, cm	pH		Adsorbed cations, meq/100 g of dry soil					v	Degree of removal or accumulation of Ca + Mg relative to the soil, %
			Water	Saline	Ca	Mg	H	Al	Total		
Kalinin	Forest	6-12	5,05	4,04	1,66	0,91	0,31	2,62	5,43	47	-71
		12-22	5,18	4,04	1,09	1,05	0,11	2,09	4,34	49	-77
		22-36	5,51	4,37	0,91	0,54	0,09	2,68	2,22	65	-84
		56-71	5,59	4,10	5,17	1,63	0,06	1,37	8,23	83	-25
		121-131	6,54	4,44	7,60	1,26	0,02	0,07	8,96	99	0 ^a
	Dry-valley meadow	0-15	6,27	4,63	3,59	1,51	0,13	0,13	5,36	95	-44
		15-28	6,28	4,36	2,73	1,45	0,22	0,08	4,48	93	-54
		28-35	5,88	4,48	4,33	2,11	0,18	0,45	7,07	91	-29
		55-67	5,45	4,04	5,17	2,54	0,04	0,57	8,32	93	-15
		117-127	6,46	6,01	7,26	2,54	0,02	0,05	9,87	99	0 ^a
Kalinin-grad	Forest	2-10	5,83	5,61	5,93	2,36	0,24	0,56	9,09	91	-8
		10-20	5,63	4,10	1,52	1,09	0,22	3,68	6,51	40	-71
		20-34	5,72	4,15	1,14	2,11	0,15	1,85	5,25	62	-64
		53-63	5,84	4,50	4,83	2,36	0,08	0,83	8,10	89	-20
		95-108	5,81	4,52	6,08	3,27	0,08	1,02	10,45	89	0 ^a
	Dry-valley meadow	0-10	6,12	4,55	5,85	1,99	0,06	0,13	8,03	98	-50
		10-21	6,07	4,90	6,65	1,49	0,04	0,07	8,75	99	-45
		21-35	6,08	5,11	6,03	2,17	0,03	0,08	8,31	98	-47
		54-66	5,82	5,15	11,78	3,85	0,04	0,11	15,78	99	0
		86-96	6,58	5,72	12,48	3,45	0,04	0,01	15,98	100	0 ^a
	Sowed perennial meadow	0-10	6,46	4,92	8,27	2,47	0,03	0,06	10,83	99	-25
		10-20	6,37	5,15	9,45	1,82	0,03	0,06	11,36	99	-21
		20-27	6,46	5,22	8,78	1,82	0,04	0,05	10,69	99	-26
		27-36	6,56	5,37	9,48	2,18	0,03	0,03	11,72	99	-19
		50-64	6,41	5,48	14,04	3,45	0,04	0,07	17,60	99	+23
	Sowed perennial meadow	84-95	6,46	5,61	10,88	1,99	0,02	0,04	12,93	100	0 ^a
	Forest	3-10	5,85	5,30	4,62	3,18	0,56	3,20	11,56	67	-65
		10-27	5,80	5,20	4,00	2,27	0,21	1,20	7,68	82	-72
		27-37	5,80	5,20	8,41	4,05	0,37	2,13	14,96	83	-44
		51-61	6,38	4,79	12,50	9,07	0,41	2,34	24,32	89	-3
		83-96	6,25	4,76	12,75	9,07	0,32	1,83	23,97	91	0 ^a
Sowed perennial meadow	Dry-valley meadow	0-14	7,42	6,80	10,75	4,08	0,03	0,15	15,01	99	-53
		14-26	7,25	6,34	8,00	3,98	0,02	0,23	12,23	98	-64
		26-37	7,18	6,31	11,42	5,26	0,02	0,18	16,88	99	-52
		47-55	6,94	6,52	16,25	12,25	0,02	0,17	28,69	100	-15
		93-106	6,24	5,46	19,12	13,62	0,03	0,03	32,80	100	0 ^a

^aIn calculating the degree of removal or accumulation of Ca + Mg relative to the soil, their average from 3-5 soil samples was taken.

Note: Comma represents decimal point.

silicates is less pronounced in the soil profile under dry valley grass vegetation and embraces only the upper part of the profile within the humus and podzolic horizons. A certain accumulation of sesquioxides also occurs in the illuvial horizon. The soils of the sowed perennial meadow in the Kaliningrad Oblast' are

characterized by the "least degree of podzolization," since Q has the lowest, even though negative, value in the upper horizons and is almost zero at a depth of 50 cm; the Al₂O₃ content is practically uniform throughout the entire profile, while its accumulation is pronounced in the residual-podzolic horizon (27-

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Table 3

Total chemical composition of soils under various types of vegetation, %

Oblast'	Land use	Horizon	Depth, cm	Total content in % of ignited soil			Total elluvial-accumulative coefficient (K) ^a	Elluvial-accumulative coefficient of the mobile part (Q) ^b	Individual alluvial-accumulative coefficients	
				SiO ₂	Al ₂ O ₃	Fe ₂ O ₃			Al ₂ O ₃	Fe ₂ O ₃
Kalinin	Forest	A ₁	4-12	83,31	7,89	2,32	-7,7	-33,3	-40,1	-47,1
		A ₂	22-36	85,12	7,86	2,43	-9,7	-41,8	-41,5	-48,6
		B ₁	36-46	78,07	11,83	3,72	-1,5	-6,4	-8,5	-14,2
		B ₁	46-56	77,76	12,27	4,19	-1,1	-4,7	-0,1	-4,9
		C	91-101	77,31	12,11	4,43				
		C	121-131	76,52	12,17	4,11	0	0	0	0
	Dry-valley meadow	A ₁	0-15	81,84	8,69	2,17	-4,5	-20,5	-30,0	-22,2
		A ₂	15-28	82,91	9,31	2,68	-5,7	-26,1	-26,2	-35,1
		B ₁	35-45	78,05	11,56	3,58	+0,2	+0,8	-2,6	-7,8
		B ₁	55-67	76,45	12,54	3,79	+4,7	+10,4	+7,9	-0,4
		C	86-97	77,84	11,83	4,31				
		C	97-107	78,52	11,94	3,47	0	0	0	0
Kalinin-grad	Forest	A ₁	2-10	82,35	7,98	2,29	-2,5	-12,9	-23,6	-45,3
		A ₂	10-20	85,75	7,42	2,17	-6,4	-32,5	-31,8	-50,3
		A ₂	20-34	84,82	7,58	2,46	-5,4	-27,3	-29,5	-43,0
		B ₁	44-53	81,34	9,66	3,39	-1,4	-6,8	-6,3	-17,8
		C	75-85	80,79	9,85	4,03				
		C	95-105	79,68	10,49	4,14	0	0	0	0
	Dry-valley meadow	A ₁	0-10	81,37	8,17	2,61	-4,1	-18,6	-26,8	-46,1
		A ₂ B	21-35	79,20	11,03	4,28	-1,5	-6,6	+0,2	-9,1
		B	35-45	77,84	11,12	4,54	+0,3	+1,2	-2,8	-2,6
		B ₁	45-54	77,92	11,06	4,69	+0,2	+0,7	+2,2	+1,3
		C	76-86	78,53	10,79	4,87				
		C	86-96	79,57	10,89	4,42	0	0	0	0
	Sowed meadow	A ₁	0-10	82,69	9,92	3,35	-2,3	-11,9	-0,9	-19,2
		A ₁	10-20	81,74	9,86	3,46	-1,2	-6,1	-0,4	-15,6
		A ₂ B	27-36	81,57	10,60	4,33	-0,9	-4,9	+7,3	+5,9
		B ₂	50-64	80,67	10,97	4,30	+0,2	+0,8	+12,3	+6,3
		C	74-85	80,86	9,74	4,00				
		C	85-98	80,73	9,83	4,10	0	0	0	0

^aTotal content of SiO₂ taken as the immobile "oxide-indicator."

^bThe coefficients Q and K were calculated according to the method of Rode (5).

Note: Comma represents decimal point.

cm) and in the illuvial horizon. The accumulation of Fe₂O₃ is also pronounced. Does the composition of the aluminosilicate portion of the soil and the migration of the decomposition products from the profile occur under grass vegetation at the present time, and to what degree? A determination of the amount of humino- and ferro-humic compounds in the profile of all soils studied showed that the migration of humic substances with sesquioxides increases with depth both under the forest and under dry meadows. This pattern becomes noticeably only in the soil of the sowed perennial meadow of the Kaliningrad

Oblast', because of the high saturation of the functional groups of humic substances with calcium. It can be thus assumed that the decomposition of the aluminosilicate portion by fulvic acids occurs in sod-podzolic soils under all types of vegetation, but it is most intense in the soils of the forest and is accompanied by a no less intense migration of decomposition products from the soil. Decomposition processes are weakened under grass vegetation because of the higher saturation of humic substances with the biogenic forms of Ca and R₂O₃, accumulating in the root system. Migration processes of these organo-mineral

compounds are apparently also weakened because of both the leaching to the bottom under meadow vegetation and the lesser mobility of the humic substances themselves, which are more saturated with Ca. This is why the decomposition and removal of the components of the aluminosilicate portion weaken in sod-podzolic soil under grass vegetation, while the biogenic accumulation of not only Ca and Mg, but also of sesquioxides, intensifies, whereby this intensity directly depends on the mass of grass and the depth to which the root system penetrates. Biological accumulation develops most intensely under grass vegetation with the participation of the productive activity of man, which must insure the improvement of the water regime, the saturation of soil with Ca, and the deep penetration of the grass root system into the soil. If this is not done, sod develops only in the upper 10-15 cm of the profile of sod-podzolic soil.

4. The influence of grass vegetation is clearly reflected in the amount and properties of the most disperse fractions of sod-podzolic

soil (Table 4). A redistribution of clay particles occurred in soils under all types of vegetation as a result of the soil formation process, so that the upper part of the soil became poor in clay particles. The removal of clay is most pronounced in the forest soil; it decreases sharply in the humus horizon under dry valley grass vegetation, but remains high in the podzolic horizon. The removal of the clay fraction is least in the soil of the sowed perennial meadow, whereby it does not increase in the residual podzolic horizon; however, there is no removal of colloids here, but a slight increase as compared to the parent material. The data obtained indicate that a renewed formation and accumulation of clay particles occurs under the influence of the grass root system, but this takes place within the 10-15 cm humus horizon and does not touch the podzolic horizon because the main mass of the root system is located in the A₁ horizon. The renewed formation and fixation of fine particles occurs most intensively in the soil of the sowed perennial meadow and embraces almost 0.5 m of the soil. The great

Table 4

Amount of the clay and colloidal fraction and the cation adsorption capacity of colloids in sod-podzolic soils

Oblast	Land use	Depth, cm	<0,001		<0,2μ			$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	Adsorption capacity, meq/100 g			
			in %	re- moval	in %	% of min- eral parti- cles	re- moval		Initial colloids		Mineral colloids	
									pH		pH	
									4,5	6,8	4,5	6,8
Kalin- in	Forest	4—12	11,9	—52	8,6	6,8	—53	2,76	81,00	95,25	38,80	41,00
		22—36	8,3	—66	6,0	5,7	—68	2,96	45,00	51,25	33,20	33,70
		46—56	25,2	+ 1	19,1	18,7	+ 3	3,00	47,25	50,00	—	—
		121—131	24,8	0 ^a	19,7	19,0	0 ^a	3,23	45,00	48,75	—	—
	Dry- valley meadow	0—15	14,2	—28	9,6	8,1	—41	2,95	76,25	84,55	43,00	46,00
		15—28	10,8	—45	7,6	7,5	—54	2,75	47,00	50,50	43,80	45,00
		35—45	21,9	+11	15,4	15,3	— 6	3,18	52,50	57,50	—	—
		117—127	21,2	0 ^a	17,2	17,1	0 ^a	3,25	49,50	52,50	—	—
Kalin- in- grad	Forest	2—10	14,3	—34	11,8	9,6	—35	2,83	84,00	96,25	45,80	47,50
		10—20	10,1	—53	8,7	8,4	—52	2,61	51,75	58,25	38,00	39,20
		44—53	18,2	—16	14,3	14,1	—23	2,87	58,75	61,25	—	—
		95—108	21,2	0 ^a	17,5	17,3	0 ^a	3,14	56,25	58,75	—	—
	Dry- valley meadow	0—10	14,7	—35	8,0	7,3	—39	3,60	67,25	75,00	50,50	54,20
		21—35	23,9	+ 6	9,5	9,4	—31	3,56	51,50	53,50	49,20	50,00
		45—54	22,0	— 3	9,0	8,9	—34	3,52	61,25	66,25	—	—
		86—96	23,2	0 ^a	14,2	14,1	0 ^a	3,53	62,00	66,25	—	—
	Sowed meadow	0—10	16,7	—26	13,5	12,5	+ 2	3,60	73,20	79,70	55,00	57,00
		27—36	19,5	—14	13,7	13,4	+ 4	3,60	65,50	68,80	62,00	63,70
		50—64	24,2	+ 7	8,5	8,4	—35	3,33	57,50	62,50	—	—
		84—95	22,2	0 ^a	11,7	11,6	0 ^a	3,49	61,70	65,00	—	—

^aIn calculating the degree of "removal" of clay and colloidal fractions relative to soil, the average from 3-5 samples was taken.

Note: Comma represents decimal point.

MODIFICATION OF SOD-PODZOLIC SOILS

oot mass, penetrating to a depth of 30-35 cm, ensures the renewal of colloidal particles, which exceeds their decomposition and removal in magnitude. Only an insignificant part of free fulvic acids in humus causes the decomposition and removal of minerals to a much lesser degree than in the soil of the dry meadow and especially under the forest.

There are considerable differences in the composition and properties of the colloids of soils under various types of land use. The colloids of the upper part of the profile of soils in the forest are characterized by the narrowest $\text{SiO}_2:\text{Al}_2\text{O}_3$ ratio. The $\text{SiO}_2:\text{Al}_2\text{O}_3$ ratio in the soil of the dry meadow, and especially in the soil of the sowed perennial meadow, is much wider and very pronounced throughout the entire profile.

The differing qualities of mineral colloidal fraction in soils under various types of vegetation is born out by data on the cation exchange capacity of the colloids. The cation exchange capacity of the colloids increases most sharply with depth in the profiles of the soils in the forest. The colloids of soils under grass vegetation have a greater exchange capacity than those of soils under the forest. Soil colloids of the sowed perennial meadow possess the greatest exchange capacity.

Thus, the synthesis and accumulation of clay

minerals are the more intense the higher the degree of development of the sod process is, which in its turn is directly dependent on the grass development.

5. Grass meadow vegetation exerts a considerable influence on the microaggregate composition of the humic horizon of sod-podzolic soils (Table 5).

As a result of the prolonged action of grass vegetation, a considerable microaggregation of silt particles occurs in the A_1 horizon. Microaggregation decreases sharply in the podzolic horizon of soils under all types of vegetation, except under the sowed perennial meadow, and increases again in the B horizon. The change in microaggregation with depth is insignificant in the soil of the sowed perennial meadow.

The aggregate composition of the soils under all types of land uses is unfavorable with the exception of the sowed perennial meadow. Only in the uppermost humus horizon of the soil in the forest, and in that of the dry meadow (10-12 cm thick) does the total amount of water-stable aggregates >0.25 mm in diameter reach 54%-66%; the podzolic horizons are practically structureless. A considerable increase in the amount of water-stable aggregates, as compared with the soil of the forest, occurs only in the soil of the sowed

Table 5
Aggregate and microaggregate composition of soils, %

Oblast'	Land use	Depth, cm	Aggregate diameter			Microaggregate diameter				K (dispersion co-efficient)
			in millimeters							
			3—1	1— 0,25	<0,25	1— 0,25	0,25— 0,01	0,01— 0,001	<0,001	
Kalinin	Forest	4—12	32,3	22,8	45,9	42,6	50,2	2,7	4,5	37,8
		22—36	3,6	16,1	80,3	26,1	65,5	6,1	2,3	28,9
		46—56	2,4	29,8	67,8	21,1	67,0	7,9	4,0	15,9
	Dry-val- ley mea- dow	0—15	47,4	17,5	35,1	30,3	64,2	4,3	1,2	8,4
		15—28	6,6	2,5	90,9	19,8	67,1	9,9	3,2	29,6
		28—35	4,8	9,6	85,6	16,9	71,6	8,5	3,0	13,6
	Forest	0—10	45,4	21,0	33,6	15,1	79,2	3,9	1,8	12,6
		10—20	13,0	27,2	59,8	12,0	79,7	6,0	2,3	10,9
		44—53	2,4	8,8	88,8	10,6	78,2	9,4	1,8	9,9
Kalin- ingrad	Dry-val- ley forest	0—10	27,3	27,1	45,6	13,4	79,1	6,5	1,0	6,8
		10—21	16,0	21,2	63,2	15,4	78,6	4,0	2,0	14,0
		21—35	6,4	22,4	61,2	10,6	75,5	11,6	2,3	9,7
		35—45	8,5	19,6	71,9	10,5	74,0	12,2	3,3	13,1
		45—54	7,0	24,5	68,5	12,0	79,5	7,2	1,3	5,9
	Sowed meadow	0—10	36,0	26,4	37,2	15,9	73,6	9,5	1,0	5,9
		10—20	32,4	29,8	37,8	14,4	73,6	11,0	1,0	5,8
		20—27	38,8	19,8	41,4	13,6	75,4	10,0	1,0	6,3
		27—36	10,1	24,8	65,1	11,0	81,5	6,5	1,0	5,1
		36—50	17,6	27,5	54,9	21,2	68,9	7,9	2,0	7,5

Note: Comma represents decimal point.

perennial meadow, where the aggregated part amounts to 60%-62% and embraces 30 cm of the profile.

The shallow penetration of the grass roots, the rapid mineralization of humic substances, and the low total content of humus, colloids, and exchangeable cations apparently result in the weak development of structural formation processes in the soils of dry meadows.

Conclusions

1. The processes of soil formation, podzolic and sod, develop in sod-podzolic soils under dry valley grass-mixed herb meadows in the European USSR. The development of soil formation is governed by the characteristics of the climatic regime under which the humification of the root residues of grass vegetation leads to the formation of a considerable amount of fulvic acids, which are leached during the periodic leaching of the soil profile.

2. The sod process, which is mainly characterized by the synthesis and accumulation of organic, organo-mineral, and mineral colloids and the accumulation of plant nutrients, develops in sod-podzolic soils under the influence of grass meadow vegetation (in the upper root zone) and cultivation. Because of the high ash content of the grass roots and the high Ca and P, as well as Si, Al, and Fe content in the ash, cations and elements of ash nutrition gradually accumulate in the root zone, even under a leaching type of regime, decreasing soil acidity. This promotes the formation of more condensed forms of humic substances and causes the gradual accumulation of colloidal particles and the synthesis of clay minerals. The degree in which the sod process manifests itself is determined by the grass yields in the meadows.

3. The degree of development of the sod

process under grass vegetation of natural dry-valley meadows may be increased by sharply increasing the yield of grass and the root residues in the soil. This may be achieved by the systematic maintenance of natural meadows — applying fertilizers and improving the botanical grass composition. However, the depth of penetration of the root system and, consequently, that of the sod process will be limited in this case by the humus-accumulation horizon. The most effective method of increasing the degree of development of the sod process is that of creating artificial planted perennial meadows and pastures over a previously built up plowed layer of 25-30 cm and then taking care of the meadows.

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METHODS

EFFECT OF THE SYSTEMATIC APPLICATION OF PHOSPHOROUS FERTILIZERS AND LIMING ON THE SUPPLY OF AVAILABLE PHOSPHATE IN SOIL

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The use of the radioactive phosphorous isotope in agricultural chemical investigations opened new possibilities for determining the content of available phosphates in soil. The radioactive phosphorous isotope was used in a number of investigations on the residual effect of phosphorous fertilizers in pot as well as in field experiments. The residual effect of phosphates is determined from the amount of available phosphates on fertilized and non-fertilized plots. The calculations are made according to the formula of Fried and Dean (7):

$$A = \frac{B(1-y)}{y},$$

where A are the available soil phosphates; B, the phosphates in the fertilizers; y, the portion of the tagged phosphorus taken up by the plants with the phosphates.

Olsen and others (10) studied the residual effect of phosphorous fertilizers on calcareous soils by determining A and comparing the data obtained with the results of chemical determinations of available phosphorus.

Similar experiments were made by McLean and Hoelscher (9), Webb and Pesek (11), Mattingly (8), and others. In spite of the conditionality of the method, the amount of available phosphates gave a satisfactory characterization of the phosphate regime of the soils in all cases. This was confirmed by yield data, the total intake of phosphorus by plants, and chemical determinations of soil phosphorus.

The objective of the present study was to determine the amount of available phosphates which accumulates in the soil as a result of the systematic application of various forms of phosphorous fertilizers and various amounts of lime in long-term field experiments on sod-podzolic soils of the Dolgoprud Agrochemical Experiment Station (DAES).

The supply of phosphates was determined by the pot method using P^{32} . In conducting the pot experiments, radioactive phosphate was added to the soil taken from the plowed layer of the experimental field plots in such small amounts that it could not influence the uptake of soil phosphates. The tagged phosphate was thoroughly mixed with the soil. The amount of available phosphates in the soil was calculated

according to the formula of A. V. Sokolov:

$$A = \frac{P \cdot 100}{K},$$
 where A is the amount of available

phosphates in the soil; P, the phosphate content in the crop; K, the percent of the tagged phosphorus taken up by the plants (5).

Soil samples used in the first experiment were taken from plots with various forms of phosphorous fertilizers. This experiment was started in 1935 on sod moderately-podzolic clay loam, which did not receive any fertilizer before the start of the experiment. The soil was under eight crop sequence rotation with clean fallow; two fields were under a mixture of alfalfa and timothy, forage beets, potato, oats, flax, and rye. The effectiveness of phosphates was measured against a background of manure and nitrogen-potassium fertilization.

During the first crop rotation manure was applied at a rate of 20 metric tons/ha to the fallow, and 20 metric tons/ha to the forage beets, that is, 40 metric tons/ha of manure per rotation. Mineral fertilizers were applied in the first rotation at a rate of 290 kg/ha N, 300 kg/ha P_2O_5 , and 225 kg/ha K_2O . During the second rotation 20 metric tons/ha of manure and 240 kg/ha of P_2O_5 were used. The experiment was ended in 1952, after five years of second rotation. Thus, 540 kg/ha of phosphorus were applied in the form of mineral fertilizers.

The forms of phosphorous fertilizers used were: superphosphate in full and half amounts, double superphosphate, dicalcium phosphate, Rhenania-phosphate, Thomas slag, ammonophos, diammonophos, and ground rock phosphate in single and double amounts. A lesser increase in yield occurred where superphosphate was applied in a half application and ground rock phosphate in a single application. The results of this experiment were described in detail in the work of Shcherba (6).

In our experiments soil from each plot was placed in four pots, two were left without phosphorus, while a radioactive solution (K_2HPO_4) of 2 mg P_2O_5 and 100 microcuries of P^{32} was added to each of the other two pots. Two pots were left without phosphorus to determine the effect of 2 mg P_2O_5 . The 2 mg of P_2O_5 had no effect on yield, nor on the uptake of

phosphorus by plants, nor on the utilization of soil phosphates, so that the results we give below are those for the average yield from four experiments.

Nitrogen and potassium ($\text{NH}_4\text{NO}_3 + \text{KNO}_3$) were applied at a rate of 0.25 g N and 0.25 K_2O to each pot as a background. The oat variety "Zolotoy dozhd" (Golden rain) was used in the experiment. Irrigation during the growing period was with distilled water to 70% of total water capacity.

During the growing period, plants on soil taken from the control plot and the plot where a background of NK and manure was applied rapidly began to lag in growth. The harvest was made during the milk stage. The results of pot experiments are given in Table 1. The experimental error is $\text{m}\bar{\text{p}} = \pm 0.52 \text{ g/pot}$.

The decrease in yield and in the removal of P_2O_5 from the soil in NK plot, as compared to the soil from plots without mineral fertilizers, must be attributed to the more intense uptake of soil phosphates by plants in the field experiment when nitrogen and potassium fertilizers are used than without these fertilizers. This is why the soil in the given plot was poorer in phosphates, which affected oat yield in the pot experiment.

The yield of oats on soils taken from the plots to which mineral fertilizers were applied increased more than two times as compared with the yield obtained from the NK + manure plot. The removal of P_2O_5 was somewhat higher from the soils taken from plots where acid fertilizers were applied than that from soils taken from plots where alkaline fertilizers were used.

The content of tagged phosphorus was insignificant as compared to the total phosphorus in plants, being only 0.3-0.4 mg of P_2O_5 per pot. It is only natural that this amount had no effect on yield.

Because of the fact that 60 metric tons of manure were applied in field experiments, the response of field crops to the applied phosphates was low, but in pot experiments the effect of phosphates from mineral fertilizers accumulated in the soils of the plots on the yield of oats was very pronounced.

The percentage of tagged phosphorus taken up was least against the background of NK + manure, and highest against the background of a half application of superphosphate. In the other samples, including the controls, the percentage of the P^{32} used was approximately the same, being slightly higher for alkaline and lower for acid forms of phosphorous fertilizers.

The total amount of available phosphates in the soil was calculated on the basis of data on the total content of phosphorus in the yield and the uptake coefficient of tagged phosphorus. These data are given in Table 2. The table also includes data on the determination of phosphorus in various extracts: a hydrochloric extract made according to the method of A. T. Kirsanov, and a hydrochloric and acetic acid extract made according to the method of F. V. Chirikov, before and after the experiment.

Analysis of the extracts shows that the content of available phosphorus in soils from fertilized plots is higher than that of background and non-fertilized plots. The hydrochloric extracts of A. T. Kirsanov gives higher results than the acetic acid extract of Chirikov. But the data from both extracts point to the accumulation of large amounts of available phosphates in the soils of the plots as a result of the application of mineral phosphorous fertilizers. After the experiment was finished, the soil was analyzed a second time. The content in the soils of phosphates soluble in acetic acid decreased almost twofold, whereby the decrease in the various samples was somehow related to the removal of phosphorus by oats in the

Table 1
Results of pot experiments with various forms of phosphates

Fertilizers applied during field experiments	Yield, g	Removal of P ₂ O ₅ , mg	Tagged phosphorous content in the yield, mg/pot	Percentage of utilized P ³²
	Per pot			
Without mineral fertilizers (manure)	6,36	18,92	0,426	21,3
NK + manure (background)	4,91	14,05	0,300	15,0
Superphosphate	12,72	34,25	0,382	19,1
Half amount of superphosphate	9,82	29,50	0,472	23,6
Double amount of superphosphate	11,15	36,42	0,460	23,0
Ammophos	11,41	35,87	0,449	22,4
Diammophos	12,62	33,27	0,392	19,6
Dicalcium phosphate	12,23	31,91	0,377	18,8
Rhenania-phosphate	11,72	29,94	0,406	20,3
Thomas slag	11,97	30,99	0,438	21,9
Ground phosphorite	12,34	30,00	0,442	22,1
Double amt. of ground phosphorite	13,72	37,26	0,409	20,4

Note: Comma represents decimal point.

PHOSPHOROUS FERTILIZERS AND AVAILABLE PHOSPHATE

Table 2

Available phosphate content in soils from experimental plots with various forms of phosphates, mg P₂O₃ per 100 g of soil

Fertilizers applied in field experiments	Extracts				De-crease in the P_2O_5 content in the CO_3-COOH extract	As-sumed supply of P_2O_5 in the soil created by fertil-izer	Supply of available phosphates in soil	
	0.2 N HCl (ac-cord-ing to Kirsan-ov)	0.5 n CH_3COOH (accord-ing to Chir-ikov)		De-crease in the P_2O_5 content in the CH_3-COOH extract			Total	Created by fertil-izers
		Before the ex-periment	After the ex-periment					
Without mineral fertilizers (manure)	4,2	5,5	2,7	2,8	2,22	—	10,4	—
NK manure (background)	5,2	3,37	3,0	0,37	1,65	—	11,2	—
Superphosphate	12,5	6,75	5,0	1,75	4,03	13,4	21,1	10,0
Half-amount of superphosphate	8,3	6,0	4,2	1,8	3,47	5,1	14,7	3,5
Double amount of superphosphate	12,5	6,0	4,3	1,7	4,28	14,7	18,6	7,4
Ammophos	10,4	6,37	2,5	3,87	4,22	14,7	18,2	7,0
Diammophos	10,4	6,5	3,3	3,2	3,9	14,8	20,0	8,8
Dicalcium phosphate	16,6	6,25	3,5	2,75	3,75	14,6	20,0	8,8
Rhenania-phosphate	12,5	7,0	3,3	3,7	3,52	14,5	17,3	6,1
Thomas slag	12,5	5,75	3,0	2,75	3,64	13,9	16,6	5,4
Ground Phosphorite	8,3	6,75	4,3	2,45	3,53	15,1	16,0	4,8
Double amount of ground phosphr.	12,5	8,25	5,82	2,43	4,38	32,4	21,4	10,2

Note: Comma represents decimal point.

ot experiment.

A certain amount of phosphates accumulates in the soil as a result of the repeated application of phosphorous fertilizers. This supply is partly used by the plants for two rotations.

If the amount of phosphorus removed by increases in yield is taken into account and deducted from the 540 kg/ha of P₂O₅ applied, the supply of phosphorus created by the mineral fertilizers will be obtained. Data on such supposed supply of phosphates are given in table 2. The amounts obtained were somewhat higher than those for the supply of available phosphates in the soil as determined from pot experiments. This probably happened because it was impossible to determine what the removal of phosphorus by the crops was in the field, since no direct analysis of all crops for P₂O₅ was made. It is also possible that part of the phosphates degenerated in the soil and changed to forms unavailable to plants.

The assumed supply of phosphates is close to the results obtained from the hydrochloric extract of Kirsanov, except for the soil with ground phosphorite, where the values are approximately two times higher, and soil to which a double amount was applied, where the values are two and one-half times higher than the results obtained from the hydrochloric extract.

The experimentally determined supply of available phosphates in soils from plots fertilized with phosphates was one and one-half

times greater than in soils from background and non-fertilized plots.

The supply of available phosphates created by the application of mineral fertilizers is so great that they must insure a prolonged residual effect of phosphorous fertilizers. The supply of phosphates in the soil corresponds to the amount of fertilizers: a half-application of superphosphates and a single application of ground phosphorite resulted in the least supply of phosphates.

Soil liming mobilizes soil phosphates and improves the phosphorous nutrition of plants. This position had already been taken by Gedroyts (3), and later by Kedrov-Zikhman (4), Askinazi and Yarusev (2), and was further confirmed in many field, pot, and laboratory experiments (1).

An improvement of the phosphate regime may be caused by two factors: an increase of the total supply of phosphates in the soil and the increase of the mobility of phosphorus. Our experiments showed that no increase of the total supply of available phosphates takes place in the soils of limed plots, only an increase in the mobility of phosphorus occurs.

We took soil samples from long-term experimental plots to which various amounts of lime were added. No phosphorous fertilizers were used on these plots. The experimental method was the same as the previous one. Table 3 gives data on the experiment with soils from limed plots. The experimental error is m_D =

Table 3

Results of the pot experiment with limed soils

Amounts of lime applied in field experi- ments, metric tons/ha	Yield, g/pot	Removal of P ₂ O ₅	Tagged phos- phorous con- tent in the yld.	Percent- age util- ization of P ³² (K)
		in mg/pot		
Without lime	6,28	12,80	0,298	14,90
13,5+4,5	10,85	21,43	0,475	23,75
22,5	9,31	24,83	0,427	21,35

Note: Comma represents decimal point.

Table 4

Influence of soil liming on the content of available phosphates, mg P_2O_5 per 100 gm of soil

Amounts of lime applied in field experiments, metric tons/ha	Extracts				Removal of P ₂ O ₅ by plants	Supply of available phos- phates
	0,5 n HCl	0,5 n CH ₃ COOH		Decrease in the P ₂ O ₅ con- tent in the CH ₃ COOH extract		
	According to Chirikov					
		Before the experiment	Aft. the experim- ent			
Without lime	12,25	2,75	1,9	0,85	1,51	10,1
13,5+4,5	20,5	4,75	2,32	1,93	2,52	10,6
22,5	16,5	2,5	1,4	1,1	2,92	13,7

Note: Comma represents decimal point.

+0.77 g/vessel. Yield, the removal of phosphorus, and the percentage utilization of P^{32} increases in the soils from limed plots as compared to the controls.

The supply of available phosphates and the phosphate content in acid extracts are given in Table 4. An increase of the phosphate content on liming is found in the hydrochloric and acetic acid extracts of Chirikov. The supply of available phosphates is approximately the same in limed and non-limed soils, but the uptake coefficient is considerably higher on liming (1.5 times). Consequently, one and the same supply of available phosphates is utilized differently: the uptake of phosphorus is considerably better in limed than in non-limed plots. Thus, to insure the phosphorous nutrition of plants on acid, non-limed soils, great amounts of phosphorous fertilizers must be applied. Because of the high uptake coefficient of available phosphates in limed soils, the phosphorous nutrition of plants may be insured by smaller amounts of phosphates.

Conclusions

1. By using tagged atoms we can determine

both the supply of available phosphates and the mobility of soil phosphates. The supply of available phosphates alone cannot be used to characterize the phosphate regime. The use made of any particular absolute amount of phosphates will differ, depending on their mobility.

2. When phosphorous fertilizers are applied systematically, both in the water-soluble and water-nonsoluble forms, large supplies of available phosphates accumulate in the soil, which may insure their long-term residual effect.

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PHOSPHOROUS FERTILIZERS AND AVAILABLE PHOSPHATE

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PROBLEM OF THE CATALASE ACTIVITY IN CERTAIN FOREST SOILS

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A great role in biochemical processes taking place in soil is played by ferments derived from the microflora, the root system of plants, and plant residues (17, 10, 9, 14, and others). Many authors believe that the activity of catalase, one of the most stable and common ferments in the plant world, is indicative of the biological state of soils.

In the opinion of Kirsanova (8), catalase may serve as an indicator of the life activity of bacteria cells in the soil; Mashtakov with his collaborators (13) established a direct relationship between the amount of microorganisms in soils, the secretion of carbonic acid, and the activity of catalase and invertase. Koepf (19), Seegerer (20), and Drobnik (6) did not find such a relationship. However, the fact has been established that soils with a high fermentative activity are characterized by an intense secretion of carbonic acid (7, 12) and a high amount of microorganisms.

Soils differ from each other by their catalase activity. Thus, catalase activity is higher in peat-bog and sod-calcareous soils than in sod-podzolic soils (15). Upland peat-bog soils are less active than low peat-bog soils and peat-humus-gleyey soils (5). According to investigations of Baranovskaya (1), chernozem soils are characterized by a higher catalase activity than sod-podzolic and chestnut soils. This author concludes on the basis of single analyses that catalase activity is higher in soils under forests in the chernozem zone than in virgin soils, while the activity of this ferment is least in soils of the same podzolic group under forests.

The literature is contradictory with respect to the seasonal dynamics of catalase activity. Some authors did not find any pattern in the variations of catalase activity in soils (18, 7), others emphasize the regularity in the changes of its activity (3, 4, 16).

In 1956 we investigated the catalase activity in forest soils of the central taiga subzone (Vologda Oblast', Kadnikov forest), those of the forest-steppe zone (Orlov Oblast', Mokhov forest), and those of the dry steppe (Lugan' Oblast', Derkul forest shelterbelt experiment station).

Air-dry soil samples and pulverized litter,

sieved through 1-mm diameter openings, were taken for analysis. All roots and plant residues were removed from the soil samples. Catalase activity was determined gasometrically from the amount of liberated oxygen according to the method of Kuprevich (11), using an electric pump. In the control samples the ferments were inactivated by heating.

The figures show catalase activity as expressed in CC's per g of air-dry oxygen substance, produced within 5 minutes, minus the oxygen formed in the control samples as a result of the activity of inorganic catalyzers. Determinations made 3 months after the initial analyses showed that catalase activity does not change in air-dry litters and soil samples.

The results of analyses in 1956 confirmed in general the results of investigations on standards and dynamics of catalase activity made in 1955 on similar samples in the Moscow forest and in a gulch forest of the Derkul station.

The catalase activity of three soil groups was studied in the Kadnikov forest, Vologda Oblast': peaty-humus gleyey soil, podzolic soil under young birches and mature spruces, and peat soils of an upland (sphagnum) and a lowland (sedge-mixed grass) bog (Fig. 1).

In examining the result attention is drawn to the high catalase activity in litters; it is more pronounced in the birch litter than in the spruce litter. The soils are characterized by a low fermentation activity. There is no significant difference between peaty-humus and podzolic soils. These soils are characterized by a BC horizon rich in inorganic catalyzers. Thus, for instance, if oxygen obtained from the B horizon in control samples of peaty-humus soil did not exceed 0.5-0.6 cm³ per g of soil, that from the BC horizon reached 6.6 cm³/g of soil. A similar phenomenon was noted by Shrova (15), Baranovskaya (1), and Vigorov (2) for soils of the podzolic group.

Catalase activity increases in litter during the growing period. However, little change in catalase activity is noticeable in the soils. Catalase activity is several times higher in the soil from the lowland bog than in the soil of the upland bog. It must be noted that the ferment activity in the upper layer (0-10 cm) of

PROBLEM OF CATALASE ACTIVITY

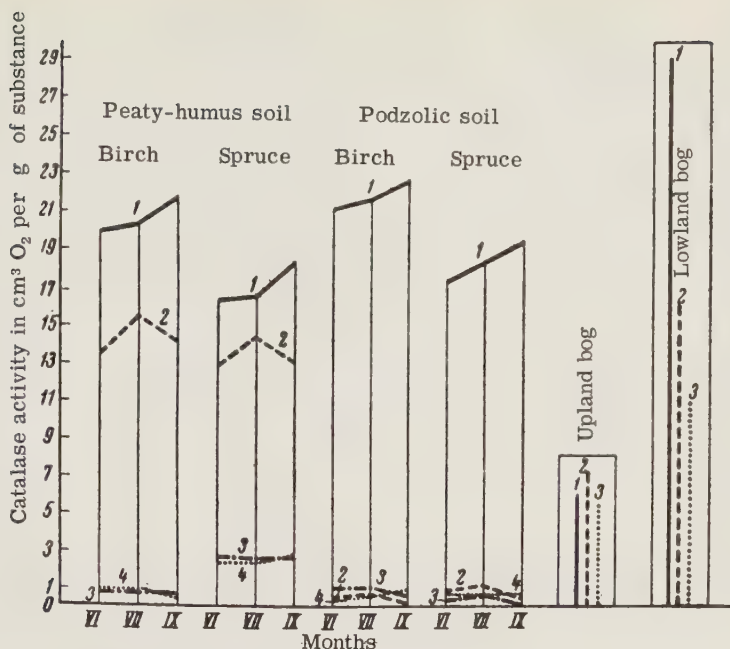


Fig. 1. - Catalase activity in the litters and soils of the Kadnikov forest, Vologda Region.

Peaty-humus soil: 1 - A₀' 0-5 cm; 2 - A₀'' 5-10 cm; 3 - A 25-30 cm; 4 - BC 45-50 cm. Podzolic soil: 1 - A₀ 0-2 cm; 2 - A₂ 0-15 cm; 3 - B 25-30 cm; 4 - BC 45-50 cm. Bog soils: 1 - A 0-10 cm; 2 - A 10-20 cm; 3 - A 20-30 cm.

the lowland bog exceeds that in the litter of birch and spruce stands on peaty-humus and podzolic soils.

Soil samples in the Mokhov forestry, Orlov Oblast', located on leached chernozem, were taken in the natural landmark of Chernikovo from under 27-year old, pure birch, oak, larch, pine, and spruce stands. The soils of forest clearing and fallow were analyzed simultaneously for the sake of comparison.

As can be seen from Figure 2, the catalase activity of litters under deciduous trees and larch exceeds that of litters under pine and spruce. The decreasing degree of ferment activity in the litters is the following: oak, birch, larch, pine, and spruce.

Soils are characterized by a lesser catalase activity than the litters. However, the difference between the activity of the ferment in the litters and in the soils is not as great as in the forest soils of the central taiga. Catalase activity decreases with depth in the soils. The upper layers of soils (0-10 cm) under deciduous trees and larch are more active than under spruce and pine; minimum activity is found under spruce. The influence of trees on catalase activity levels down in the lower layers.

The ferment activity in the soils from the forest clearing and from the fallow is lower than under the forest, even though catalase activity is higher in the forest clearing than in the fallow.

As far as seasonal changes are concerned, maximum catalase activity in the litters occurs in July and in soils, in August. The dynamics of the activity of the ferment is similar in various soil layers.

At Derkul station, Lugan' Oblast', soils samples were taken from slightly humic calcareous chernozems in a gulch forest (Stenki village) under stands 20 years old (compartments 25 and 27). The stand in compartment 25 is represented by: a) oak, b) oak, Norway maple and yellow acacia; and in compartment 27 by: a) oak, b) oak and ash, c) oak, ash, and yellow acacia.

For comparison with soils from under plantations, samples of fallow soil were taken from between rows of 3-year old oaks, located in the vicinity.

In the gulch forest samples were taken from profiles located along the slope of a dry gulch exposed to the northwest. The first profile was made on the watershed under oak and ash plantations 10 years old; the soil was a shallow ordinary chernozem. The second profile was made on the gentle slope of watershed in a maple-shrub oak stand, with a gray forest soil. The third profile was made in the second third of the slope in a maple-shrub oak stand with a gray forest soil. The fourth profile was made at the slope of the gulch in an birch-goutweed oak stand with meadow-forest chernozem-like soil.

Analyses of the catalase activity, shown in

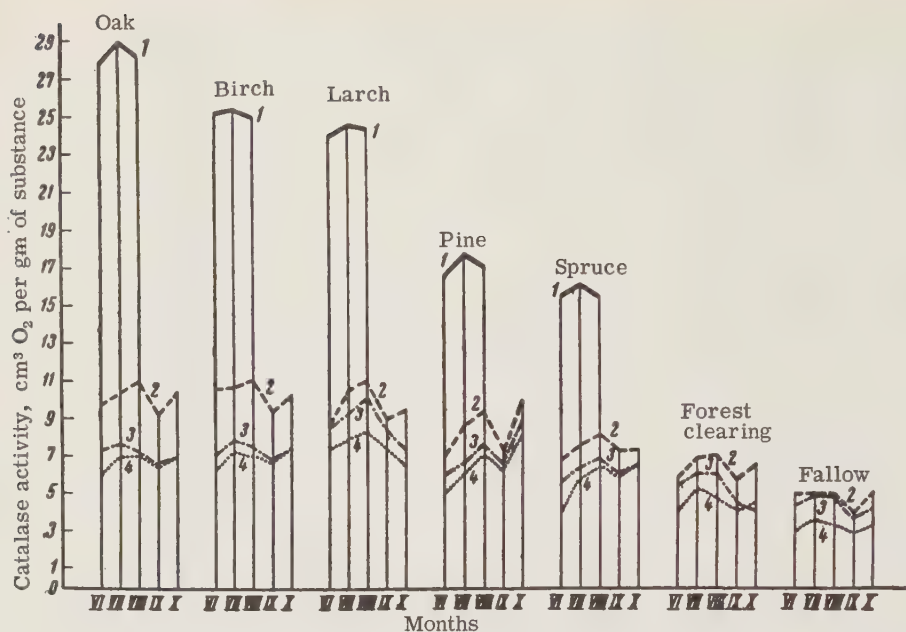


Fig. 2. - Catalase activity in litters and soils of the Mokhov forest, Orlov Oblast'.
1 - A₀ 0-2 cm; 2 - A 2-10 cm; 3 - A 10-20 cm; 4 - A 20-30 cm.

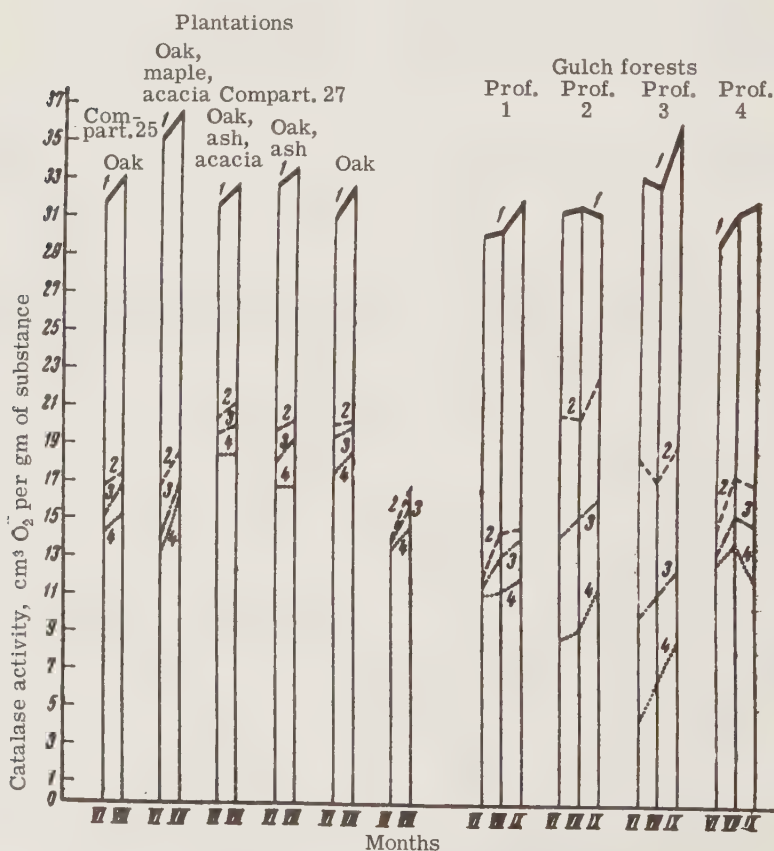


Fig. 3. - Catalase activity in litters and soils of the Derkul forest experiment station, Lugan' Oblast'

1 - A₀ 0-2 cm; 2 - A 2-10 cm; 3 - A 10-20 cm; 4 - A 20-30 cm.

PROBLEM OF CATALASE ACTIVITY

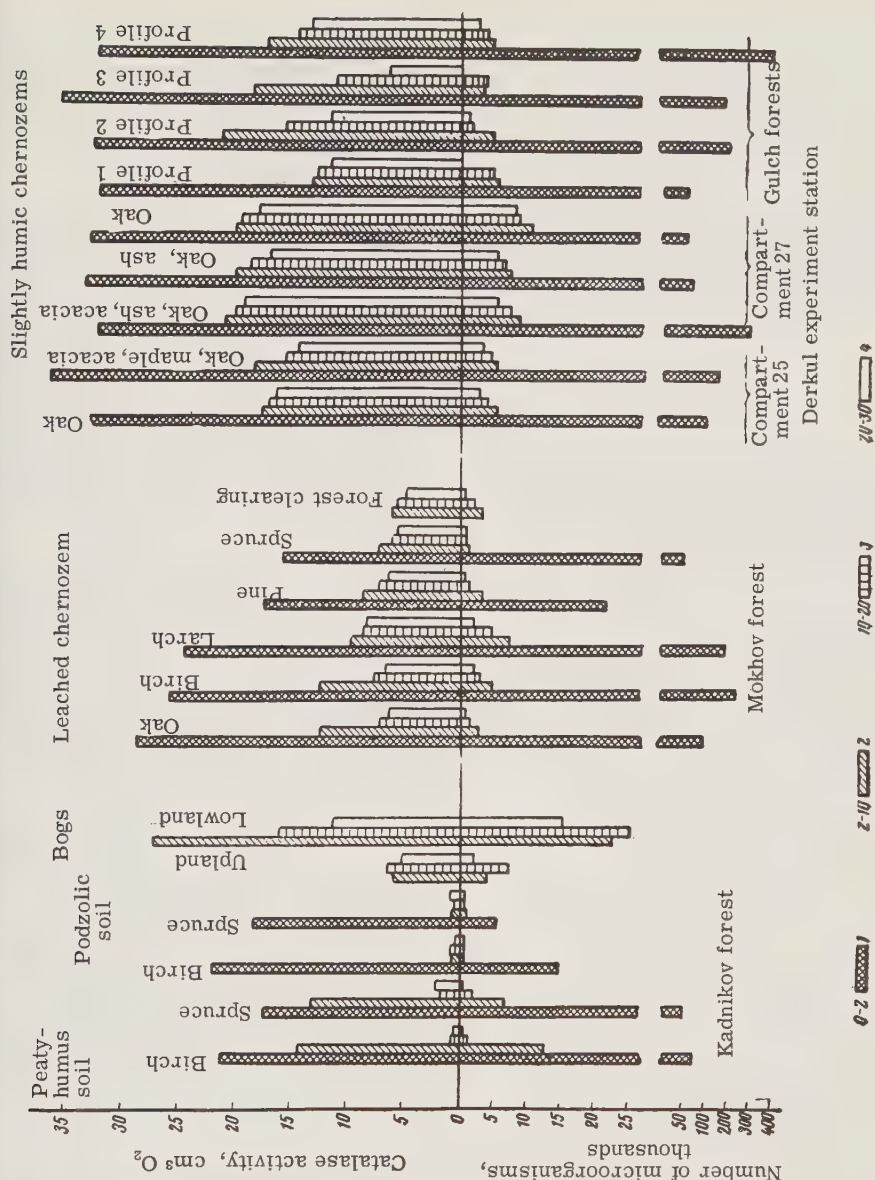


Fig. 4. - Number of microorganisms and catalase activity of forest litters and soils (average values)

1 - 0-2 cm; 2 - 2-10 cm; 3 - 10-20 cm; 4 - 20-30 cm.

Figure 3, confirm the general opinion on the thickness of litter in catalase. Its activity depends on the composition of the forest stands and on other factors. Thus, catalase activity is lower in the litters of pure oak stands than in mixed stands. The admixture of various trees to oak is reflected differently in the ferment activity in litters. The presence of maple is especially favorable. In the gulch forest the litter of the oak stand on the slope of the gulch stands out particularly (Profile 3). Judging from the analysis of the upper layers, there is a tendency for catalase activity to increase in litters from the plantations with mixed species of trees.

Trees have a positive effect on the catalase activity in soil. This follows from the comparison of values for soils under woody vegetation and from the fallow in the rows between 3-year old oak plantations, where catalase activity is the least. The same picture is observed for the soils in the gulch forest (Profiles 2, 3, and 4) and adjoining young plantations (Profile 1). The highest activity of the ferment in the 0-10 cm layer was found in the soil of Profile 2 in the gulch forest; the activity decreased downwards and reached a minimum in the entire soil layer investigated (down to 30 cm) in Profile 3.

Figure 4 gives average data on the catalase

activity in litters and soils, and the total content of microorganisms in them, such as bacteria, actinomycetes, and microscopic fungi, determined by the culture method (bacteria in meat-peptone agar, actinomycetes in starch-ammonia agar, and fungi in wort-agar).

The catalase activity in litters and soils generally increases from north to south. There is a certain interrelationship between the level of catalase activity and the number of bacteria, even though there is no strict parallelism between the two. The activity of the ferment increases with the increasing number of microorganisms.

Conclusions

1. The catalase activity of forest litters and soils is associated with the composition of trees and soil group. The activity of the ferment under evergreen conifers (spruce and pine) is depressed as compared to that under deciduous trees and larch.

2. Litter, in contrast to soils, is characterized by high catalase activity.

3. Woody vegetation promotes the increase of catalase activity in soils. The ferment is most active in the upper soil layers and its activity decreases with depth.

4. In the growing season, catalase activity in litters and soils increases toward autumn.

5. There is a certain interrelation between the level of catalase activity and the number of microorganisms in litters and soils.

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BORON IN THE SOILS, COTTON, IRRIGATION AND GROUND WATERS OF GOLODNAYA STEPPE

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Because of the future irrigation and reclamation for cotton in soils of the Golodnaya Steppe it was found necessary to study their agricultural chemistry.

The investigations were made using the method of "key" areas, representative of the most common and typical soil and other conditions (see the schematic map, Profiles I, II, III, V, and VI).¹

According to the description of Suchkov (7), the land reserves for the future irrigation of Golodnaya Steppe consist of two large geomorphological soil areas:

1. The central part of the steppe, which is geomorphologically associated with the trains of old alluvial fans, is represented by light-colored, medium, and fine clay loam sierozems, developed on thick, thinly stratified clay loam and clay deposits with deep, mineralized ground waters which have no influence on soil formation (Profile I in Fig. 1).

2. The southern part of the steppe is geomorphologically associated with the depressed, winding valleys of recent alluvial cones and is represented by light-colored, gleyey solonchaks and sierozems, primarily of the sulfate type of salinization. The ground water stands high. Profile II was made here.

Profiles III, V, and VI were made in the reclaimed part of Golodnaya steppe, in the valley of the third flood-plain terrace in light sierozems and gleyey sierozems and represent, respectively: the initial stage of reclamation (years), the oldest reclamation (50 years), and reclamation most typical in age (30 years).

The characteristic features of the areas studied are (Table 1): a general moisture deficiency and a need for irrigation if the land is used for agriculture; intense and prolonged

insolation; alkalinity of the soil solution ($\text{pH} > 7$); a high oxygen potential leading to a high degree of oxidation; highly carbonate soils; a comparatively low content of organic substances (0.6%-1.0% in the plowed layer); and a low adsorption capacity (10-5 meq/100 g of soil). Adsorbed cations contain about 80% Ca^{++} of the total adsorption capacity; microbiological activity is high (provided the soil is moist); and there are upward flow solutions in top soil, and often subsoil, (2, 3, 4, and others).

The sources of boron in the virgin soils of Golodnaya Steppe may be: parent material; atmospheric precipitation, primarily eolian; and ground waters.

Under irrigation and soil cultivation an important role is played by the addition of boron by irrigation waters and the mud carried with it, as well as by organic mineral and earth (local) fertilizers.

Four forms of boron are contained in the soils (9): 1) aluminoborosilicates in compounds of the type of tourmaline, which are insoluble even in strong concentrated acids; 2) organic boron compounds; 3) calcium, magnesium, and more rarely, sodium borates; some of these of the type of $\text{NaCaB}_5\text{O}_9 \cdot 8\text{H}_2\text{O}$ ulexite, are soluble in hot water, but most of them are soluble only in acids (3); and 4) boric acid compounds which are soluble in water, especially boiling.

Total Boron Content in the Soils

The total boron content in the soils was determined in the following steps: 1) decomposition of soil by fusion with sodium and potassium carbonates; 2) separation of boron from other components of the melt by distillation as boromethyl ether, 3) removal of the organic material (residues) by ignition, and 4) photocolourimetry of the carmin-colored solution, dyed with carmin, in an FEK-M photocolourimeter (4).

The results, given in Table 2, show that light-colored sierozems of Golodnaya Steppe contain 11-22 g percent boron. These data confirm the opinion of Vinogradov (1, p. 35) that the Aral-Caspian lowland and the regions east of it as well as regions "located along the

¹The soil samples were taken for complex investigations of their chemical, physical, and microbiological properties and described by the chief of the Agricultural Soil Science Section of the Central Station of Fertilizers and Agricultural Soil Science of the State Scientific Research Institute of Cotton Cultivation, Suchkov (7).

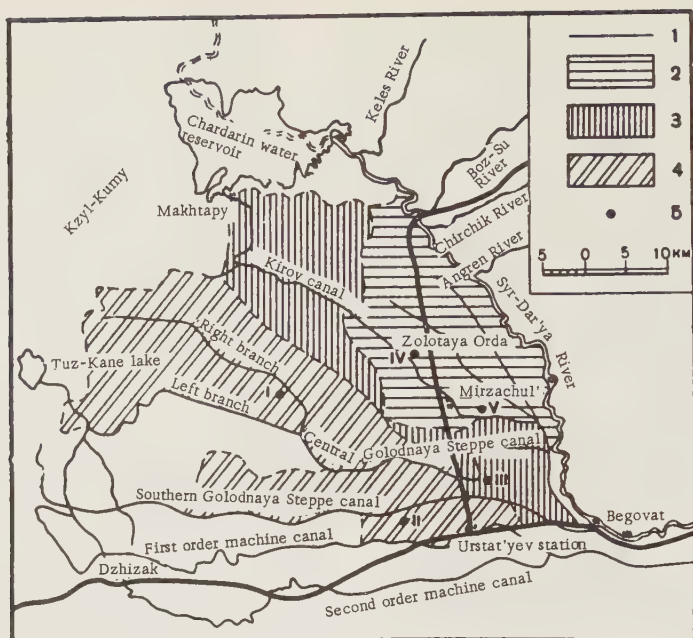


Fig. 1. - Schematic map of Golodnaya Steppe

1 - irrigation channels; 2 - lands cultivated before 1917; 3 - lands cultivated after 1917; 4 - lands being reclaimed; 5 - soil profiles.

break in the earth's crust of the Mediterranean geosyncline, extending in a belt in Eurasia in a latitudinal direction almost from Gibraltar to the shores of the Pacific, "have soils most rich in boron.

The primary reason for the accumulation of boron in the soils of Golodnaya Steppe was the fact that "this depression and the adjoining foothills were occupied by a shallow sea during the Lower Tertiary, which deposited a layer of salt-bearing materials" (5). As may be seen, these salt-bearing materials are enriched with boron.

The distribution of boron along the soil profile depends in each individual case on the characteristics of the landscape and other factors. But, the more saline is the soil horizon, the more boron it contains, as a rule. The cultivation of soil (leaching irrigation, etc.) lowers the total boron content to a depth down to one meter. No great accumulation of boron was found in the plowed horizon of the soils investigated (as is usually found in other soils).

The borosilicate content of soils was determined from the difference between total boron and boron dissolved in acid (Table 3). Before determining acid-soluble boron in carbonate soils, the quantity of acid necessary to decompose the carbonates must be determined.

Method of Determining Acid-Soluble Boron

Twenty grams of air-dried soil are treated

with a titrated solution of 0.1 N HCl, shaken, and left overnight. The solution is boiled for 10 minutes in a reflux condenser and filtered while hot. Twenty mls of the filtrate are titrated with 0.1 N NaOH with methyl red. The amount of 1 N HCl necessary to decompose the carbonates in 20 g of soil is determined by appropriate calculations.

Preparation of the extract: 20 g of air-dried soil are treated with 100 ml of 0.1 N HCl (titrated solution); 1 N HCl is immediately added to the solution in the amount necessary to decompose the carbonates, the solution is shaken and left overnight. The solution is boiled in the morning for 10 minutes in a reflux condenser and filtered while hot.

Fifty mls of the transparent filtrate are placed into a quartz, or platinum dish, made alkaline with concentration KOH (until a precipitate forms), and evaporated in a water bath. The contents of the dish are transferred in a small amount of water into a quartz distillation flask and evaporated until dry. The flask is connected to the apparatus for the distillation of boron in the form of boromethyl ether. Then boron is determined by the usual method (4).

The results of the determinations of acid-soluble boron are given in Table 2 and show that its amount varies from 3.1-6.2 mg %, which is 19%-45% of the total amount of boron i. e., in the light-colored sierozems investigated, the boron compounds in the form of aluminoborosilicates comprise 55%-81% of the

GOLODNAYA STEPPE SOILS

Table 1

General characteristics of soils studied in the Golodnaya Steppe

Profile No.	Location of profile	Soil	Degree of cultivation	Horizon and depth, cm	Solid residue	CO ₂	pH
					in %		
I	Central loess massif	Light-colored, medium, clay loam sierozem, horizon C, loess-like clay loam. Ground water at a depth of 17,5 m	Virgin land	A 0—28 B 18—28 B 28—40 B 40—50 C 90—100	0,26 0,28 0,13 0,16 0,18	8,18 14,5 15,3 13,7 12,3	7,3 7,3 7,3 7,3 7,3
VI	Northern course of Kirov canal. Il'ich kolkhoz	Light-colored, medium clay loam sierozem, C horizon, loess-like clay loam. Ground water is deep	Irrigated for 30 years	A 0—28 B 28—42 C 90—100	0,28 0,17 0,12	16,0 19,2 18,6	7,4 7,4 7,4
II	Southern massif, western part of the Southern Golodnaya Steppe canal	Light-colored, silty clay loam sierozem on stratified deluvium and proluvium. Ground water at a depth of 4 m	Virgin land	A 0—16 A 16—30 B 30—40 B 40—50 C 90—100	2,18 2,12 2,50 3,08 2,90	8,3 9,2 11,2 12,5 19,3	7,1 7,2 7,2 7,2 7,2
III	Southern massif, eastern part. Bayaut No. 4 sovkhos	Light-colored, clay loam sierozem, C horizon, loess-like clay loam	Irrigated for 3 years	A 0—28 B 28—40 C 95—100	0,18 0,23 2,10	17,6 17,0 14,8	7,4 7,4 7,3
V	Mirzachul' region. October kolkhoz	Light-colored, moderately clay loam sierozem, C horizon, clay loam	Irrigated for more than 50 years	A 0—30 B 30—50 C 85—100	0,20 0,34 0,76	16,7 17,7 18,8	7,1 7,1 7,1

Note: Comma represents decimal point.

total boron content (Table 3). An increase in acid-soluble boron compounds was found in the plowed horizon.

Water-Soluble Boron

To characterize the most readily soluble boric acid compounds in soils, a soil extract can be made at a temperature from 20°-25°C (1:5). But to determine the total amount of water-soluble boron in soils one must make soil extracts with boiling water (1, 4). Only 0.004-0.028 mg % of boron is extracted from a water extract at 20°-25°C which is 0.04%-0.1% of the total boron content.

Boron varied from 0.04-0.5 mg % in the boiling water extract of the soils studied, which is 0.36%-3.1% of the total boron content. The

results obtained (Table 2) show that the content of water-soluble boron is high along the entire profile down to 1 m in all soils studied in the Golodnaya Steppe. The amount of water-soluble boron decreases on cultivated soil parallel with the decrease in total salinity. A slight accumulation of water-soluble boron occurs in the plowed horizon of old cultivated soils, which is apparently associated with its biological accumulation.

Boron in Irrigation and Ground Waters. The soils studied in the Golodnaya Steppe may become enriched in boron salts from irrigation water, since the irrigation water in cotton fields has usually no outlet.

The ground waters are generally highly mineralized and their boron content is almost a hundred times higher than that of irrigation

Table 2

Boron and its forms in the soils of Golodnaya Steppe, mg %^a

Profile No.	Soil	Depth, cm	Boron			
			Total	Acid-soluble	Water-soluble	
					At boiling	At 20°C
I	Non-saline light-colored sierozem. Ground water is deep. Virgin land	0—18	13,0	5,9	0,08	0,010
		18—28	12,0	5,5	0,08	0,011
		28—40	12,0	5,5	0,08	0,010
		40—50	12,0	3,0	0,04	0,006
		90—100	11,0	3,1	0,04	0,005
VI	Non-saline, light-colored sierozem. Ground water is deep. Irrigated for 50 years	0—28	14,0	6,2	0,33	0,017
		28—42	14,0	5,0	0,14	0,008
		90—100	11,0	5,0	0,11	0,004
II	Light-colored, salinized sierozem. Ground water at a depth of 4 m. Virgin land	0—16	19,0	5,0	0,35	0,018
		16—30	15,0	4,6	0,25	0,012
		30—40	16,0	5,0	0,50	0,020
		40—50	21,0	4,6	0,35	0,018
		90—100	22,1	4,2	0,32	0,010
III	Non-saline, light-colored sierozem, leached by irrigation. Ground water at a depth of 4 m. Irrigated for 3 years	0—30	16,0	5,2	0,33	0,016
		30—40	15,0	4,6	0,31	0,012
		90—100	18,0	4,0	0,50	0,028
V	Non-saline, light-colored sierozem. Ground water at a depth of 4 m. Irrigated for more than 50 years	0—30	15,0	5,0	0,25	0,015
		30—50	14,0	4,3	0,15	0,010
		85—100	15,0	4,0	0,25	0,015

^aMilligram percent = 0.001%.

Note: Comma represents decimal point.

waters (Table 4).

Boron in Cotton. The most reliable data on the content of available boron in soils may be obtained by analyzing the plants themselves (Table 5).

The highest amount of boron was found in cotton leaves in the Bayaut No. 4 sovkhoz, where the soil contained the highest amount of water-soluble boron to a depth of 1 m (Profile III).

Representative data on the availability of soil boron to plants were obtained from the analysis of the leaves of cotton grown in pots filled with soil from various parts of the profile.

Table 6 shows that the availability of boron compounds to cotton varies unevenly in various soil layers, but that it generally correlates with the content of water-soluble boron.

To approximately judge about the removal

of boron from the soils by the cotton crop, calculations were made which are shown in Table 7.

In growing 1 metric ton of raw cotton, 113.2 g of boron were recommended from the soil in Bayaut No. 4 sovkhoz (Profile III), 64.9 g, in October kolkhoz (Profile V), and 53.2 g in Il'ich kolkhoz.

Conclusions

1. Light-colored, non-saline sierozems of Golodnaya Steppe contain 11-13 mg % of boron. The boron content increases to 22.1 mg % in salinized soils.

Soil cultivation (reduction of total salinity as a result of a number of agricultural practices, the removal of boron by the crop, etc.) reduces the total boron content to a depth down to 1 m.

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Table 3

Mobility of boron in the soils of Golodnaya Steppe

Profile No.	Soil	Depth, cm	In % of the total amount of boron			
			Alumino-borosilicates	Acid-soluble borates	Water-soluble borates	Boric acid compounds
I	Non-saline, light-colored sierozem. Ground water is deep. Virgin land	0—18	54,6	45,4	0,61	0,09
		18—28	70,9	29,1	0,66	0,09
		28—40	70,9	29,1	0,66	0,08
		40—50	75,0	25,0	0,33	0,05
		90—100	71,9	28,1	0,36	0,04
VI	Non-saline, light-colored sierozem. Ground water is deep. Irrigated for 30 years	0—28	55,6	44,4	2,3	0,12
		28—42	64,3	35,7	1,0	0,06
		90—100	54,6	45,4	1,0	0,04
II	Salinized, light-colored sierozem. Ground water at a depth of 4 m. Virgin land	0—16	73,7	26,3	1,8	0,09
		16—30	69,4	30,6	1,6	0,08
		40—50	68,7	31,3	1,5	0,12
		90—100	81,0	19,0	1,4	0,04
III	Non-saline, light-colored sierozem, leached by irrigation. Ground water at a depth of 4 m. Irrigated for 3 years	0—30	67,5	32,5	2,0	0,10
		30—40	70,0	30,0	2,0	0,08
		90—100	77,8	22,2	2,7	0,15
V	Non-saline, light-colored sierozem. Ground water at a depth of 4 m. Irrigated for more than 50 years	0—30	66,7	33,3	1,6	0,10
		30—50	69,3	30,7	1,0	0,07
		85—100	73,4	26,6	1,6	0,10

Note: Comma represents decimal point.

Table 4

Boron in irrigation and ground water, g/liter

Profile No.	Sampling area	Water	Solid residue	Boron
V	Mirzachul' region, October kolkhoz	From Kirov canal	0,47	$1,9 \cdot 10^{-5}$
		From the main irrigation canal	0,46	$1,3 \cdot 10^{-5}$
V	Same	From a furrow in the cottonfield, 70 m from the main irrigation canal	0,51	$1,0 \cdot 10^{-5}$
VI	Il'ich kolkhoz	From the irrig. can. in the cotton fd.	0,68	$1,9 \cdot 10^{-5}$
V	Mirzachul' region, October kolkhoz	Ground water at a depth of 175 cm, cotton field	2,43	$3,0 \cdot 10^{-5}$
VI	Il'ich kolkhoz	Ground water at a depth of 210 cm	17,23	$1,6 \cdot 10^{-3}$
III	Bayaut No. 4 sovkhov	Ground water	72,28	$1,2 \cdot 10^{-3}$
I	Virgin land	Ground water at a depth of 17.5 m	23,38	$3,1 \cdot 10^{-3}$

Note: Comma represents decimal point.

Table 5

Boron in the organs of cotton grown on the soils studied

Profile No.	Sampling area	Boron, mg %					In % of total boron				
		Leaves	Stalks	Pod	Seed	Fiber	Leaves	Stalks	Pod	Seed	Fiber
III	Bayaut No. 4 sovkhov	12,5	2,6	2,8	2,5	0,01	61,2	12,7	13,7	12,2	0,2
V	October kolkhoz	8,0	2,3	2,5	1,3	0,01	56,7	16,3	17,7	9,2	0,1
VI	Il'ich kolkhoz	7,0	1,2	2,0	1,3	0,01	60,8	10,4	17,3	11,3	0,2

Note: Comma represents decimal point.

Table 6

Boron in the leaves of cotton grown in pots, mg %

Sampling area	Depth, cm		
	0—20	20—40	40—60
Bayaut No. 4 sovkhov	10,2	9,7	12,0
October kolkhoz	9,1	Virgin land	5,2
Virgin land	9,3	3,7	3,1

^aThe experiment was made by the agricultural sciences candidate, P. V. Protasov, Central Station of Fertilizers and Agricultural Soil Science of the State Scientific Research Institute of Cotton Cultivation, 1957.

Note: Comma represents decimal point.

Table 7

Removal of boron with cotton crop

Organs of cotton	Bayaut No. 4 sovkhov		October kolkhoz		Il'ich kolkhoz	
	Yield, cntr/ha of air-dry mass	Boron removal, g/ha	Yield, cntr/ha of air-dry mass	Removal of boron, g/ha	Yield, cntr/ha of air-dry mass	Removal of boron, g/ha
Leaves	10,27	128,3	15,99	127,9	12,70	88,9
Stalks	6,80	17,68	13,60	31,2	10,80	12,96
Seeds	11,30	28,25	21,79	28,3	17,60	22,88
Pods	6,30	17,64	13,52	33,8	10,80	18,80
Fiber	5,70	0,57	12,21	0,12	9,40	0,1
Total		192,44		221,3		143,64

Note: Comma represents decimal point.

There is no sharp accumulation of total boron in the plowed horizon, the highest boron content is most often found in the C horizon.

Boron compounds in the form of aluminosilicates (55%-81% of total boron) predominate in the light-colored sierozems studied. The content of acid-soluble boron compounds increases in the plowed horizon of soils that have been cultivated for a long time.

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2. The light-colored sierozems of Golodnaya Steppe contain 0.04-0.5 mg % of water-soluble boron, which is 0.36% of the total boron. The content of water-soluble boron is high throughout the profile of all soils to a depth of 1 m. When the soil is cultivated, the amount of water-soluble boron decreases (with the decrease in general salinization, etc.). Water-soluble boron accumulates somewhat in the plowed horizon soils cultivated for a long time.

3. The irrigation waters of Golodnaya Steppe, derived from the Syr-Dar-ya River and the Kirov canal, contain $1.0-1.9 \times 10^{-5}$ g of boron per liter.

The ground waters are mostly highly mineralized and have a high boron content reaching 3.1×10^{-3} g of boron per liter.

4. The availability of boron compounds in the soils studied to cotton correlates with its content in the water-soluble form. When growing 1 metric ton of cotton, the amount of boron removed from the soil is 113.2 g in the Bayaut No. 4 sovkhoz (Key III on map), 64.9 g in the October Revolution sovkhoz (Key V on map), and 53.2 g in the II'ich kolkhoz (Key VI on map).

5. The high content of total and water-soluble boron in the light-colored sierozems of Golodnaya Steppe (especially in the salinized ones) may be considered as a provincial soil characteristic.

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SIGNIFICANCE OF THE ADSORPTION OF CATIONS WHEN DETERMINING CLAY MINERALS IN CLAYS AND SOILS

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The problems discussed in this article concern the diagnosis of clay minerals in clays and soils by means of heating curves. Thermal analysis is ordinarily used to study the fine fractions of clays and soils (particle diameters <0.001 mm or colloids). The high dispersion and polyminerality of these fractions are the cause for a number of special clay and soil properties which complicate the determination of their mineral composition by means of heating curves. One such property is the high adsorption capacity for water and alkali and alkaline earth cations. The adsorption capacity of clay minerals is determined not only by their degree of dispersion, but also by the nature of their crystal structure.

Clay minerals are hydrous silicates of alumina, iron, and magnesium with a layered structure consisting of alternating silicate and alumina-hydroxyl layers. The structure of clay minerals may be two-layered and consist of one silicate and one alumina-hydroxyl layer, and three-layered, consisting of two silicate layers and one alumina-hydroxyl layer between them. In the case of three-layered minerals, isomorphic substitutions of one cation by another are possible, which leads to a change in the magnitude of charges on the inner surface of the minerals and may increase, or decrease, their adsorption capacity.

Another widespread type are the mixed-layer structures, which most often consist of combinations of montmorillonite and illite layers of similar type, or attachments of two-layered kaolinite and three-layered montmorillonite layers (2, 4, 6).

All clay minerals of the foregoing structural types are encountered in soils: 1) kaolinite and halloysite, which have a two-layered structure; 2) minerals of a mixed-layer structure consisting of hydromica and beidellite (or montmorillonite) layers; 3) hydromicas of variable composition, which have a three-layer structure and are represented in soils by several minerals, the most common of which is illite (beidellitized hydromica).

Montmorillonite and beidellite, as such, are apparently found in soils only in the form of an admixture. Nontronite extremely rarely predominates in the fine fraction of soils.

Each of the minerals mentioned has its own characteristic heating curve, except for mixed layer minerals, the heating curves of which vary greatly. In examining a thermogram of the <0.001 mm diameter fraction of soils, we often observed deviations from the heating curves typical for any of the groups of clay minerals. These deviations appear as additional thermal effects, as a relative decrease, or increase, in the area of this or that thermal effect, or, finally, as a displacement of their temperature. It is usually believed that such deviations are caused by the presence of thermally active impurities, inert crystalline or amorphous substances, or a mixture of two or more clay minerals. In speaking of mixtures we mean not just mechanical mixtures, but also the more intimate mixtures consisting of interpenetrating layers or attachments of clay minerals, which mentioned earlier; in this case the heating curves here are different from those in the curves for mechanical mixtures.

In addition to the effects of impurities and mixtures of minerals, the heating curves of clays and soils are influenced by cations adsorbed on the outer and inner surfaces of clay minerals.

Caillère and Hénin (11) were concerned as early as 1939 with the change in the intensity of the exothermal effect of kaolinite caused by adsorbed cations. As clay becomes saturated with cations, the effect decreases. The cations fall in the following order of decreasing exothermal effect: $\text{Ca}^{++} > \text{K}^{+} > \text{Fe}^{+++}$. In later works (13), the same authors established that not only the but also the Al and NH_4^{+} ions, increase the exothermal effect of kaolinite, while the ions of alkaline metals decrease it.

Caillère and Hénin are the only ones to have investigated the influence of adsorbed cations on the heating curve of kaolinite. The heating curve of montmorillonite has been studied in more detail. In 1940, Hendricks, Nelson, and Alexander (16) studied the mechanism of hydration of montmorillonite saturated with various cations. From the first endothermal effect on the heating curve they established the difference in the nature of hydration of various montmorillonite samples saturated with various cations. Our investigation (9) confirmed the conclusions of the foregoing authors.

Caillère and Hénin (12) traced the effect of H^+ , Na^+ , Mg^{++} , Ca^{++} , Ba^{++} , Al^{+++} , Fe^{+++} , and NH_4^+ on the heating curve of montmorillonite and established that under the influence of Na^+ and Al^{+++} the first endothermal effect decreases, while under the influence of Na^+ , Al^{+++} , and Fe^{+++} the second endothermal effect increases; the third endothermal effect is almost completely nullified in the presence of Na^+ and decreases from Fe^{+++} . The Al^{+++} increases it noticeably. The exothermal effect increases when montmorillonite is saturated with Al^{+++} , H^+ , and NH_4^+ , while alkali and alkaline earth cations decrease it.

In investigating the effect of interlayer cations on a crystal lattice of the mica type, Barshad (10) found that the low-temperature effect has a single peak on the heating curves of Na , K , NH_4 , Rb , and Cs montmorillonite, and two or three peaks for samples saturated with Mg^{++} , Ca^{++} , Ba^{++} , H^+ , and Li^+ . Adsorbed cations influence the exothermal reaction at the temperature of incandescence. In his work, devoted to the hydration of montmorillonite, Mackenzie (17) noted a single endoeffect for Na-montmorillonite and explains it by the absence of hydration of the Na^+ .

The investigations of Mackenzie and Bishui (18) showed that exchangeable cations also affect the temperature at which the endothermal effect of the removal of constitutional water from montmorillonite (dehydroxylation reaction) occurs. This is a parabolic function of ionic radii and is independent of their valence. For instance, the dehydroxylation of montmorillonite saturated with Li^+ and Mg^{++} , having radii of 0.78 Å, occurs at about 680°C; that of montmorillonite saturated with Ca^{++} (radius 1.06 Å) occurs at 710°C, etc.

As may be seen from the literature, the problem of the significance of adsorbed cations for the thermographic study of clays and soils has not been sufficiently investigated. There are no data on those clay minerals which are most common in soils, such as hydromica, beidellite, and mixed-layer formations. There is no satisfactory explanation of the causes of certain changes in the heating curves under the influence of adsorbed cations and there are absolutely no experimental data on the influence of adsorbed cations on the heating curves of the fine fraction of soils.

This paper examines the <0.001 mm diameter fraction in clays and soils containing two and three-layered clay minerals, minerals of a mixed-layer structure, and mixtures of clay minerals.

1) Pologi kaolin contains kaolinite with an admixture of halloysite. 2) Askanite from Tsikhis Uban consists of more than 90% montmorillonite. 3) L'vov¹ clay. Chemical analysis and a special lithium test for montmorillonite indicate the presence of a hydromica and montmorillonite component in this clay. A detailed x-ray analysis of this sample by Kukov-

skiy (5) showed that the structure of L'vov clay consists of an "orderly alternate interstratification of packages of montmorillonite and hydromica structural cells." 4) Kiev clay. Thermal, x-ray and chemical analyses showed that Kiev clay contains kaolinite and a three-layered mineral with an expanding lattice. An electron-microscope photograph indicates the presence of a mica (or hydromica) component in the form of individual large, semi-transparent lamina. X-ray investigations of the same sample of Kiev clay by Kukovskiy (5) showed that it is a mixture of hydromica and kaolinite.

We investigated the <0.001 mm diameter fraction of the following: 1) ordinary chernozem on loess-like clay from Kamennaya Steppe (Profile 45, depth 56-61 cm), 2) ordinary chernozem on basalt from Armenia (Profile 593, depth 48-53 cm), and 3) southern chernozem on red-colored Tertiary clay from the Rostov Oblast' (Profile 504, depth 95-100 cm).

The samples of the clay fraction of the foregoing clays and soils were saturated with the cations most common in clays and soils, such as H^+ , Na^+ , and Ca^{++} . Saturation with H^+ was achieved by treating the suspension extracted from the clay fraction of the samples with hydrochloric acid. Saturation with Na^+ and Ca^{++} cations was achieved by treating the clay fraction with a buffer mixture of 0.1-N solutions of the corresponding salts with a pH of 7. After saturation, the samples were first washed with water and then with alcohol, dried on a water bath, kept in a desiccator at 50% relative humidity² for 5 days, and subjected to thermal analysis. The samples were treated with 30% hydrogen peroxide to remove the organic material. Samples of 2 g and 1.5 g were taken for analysis. The heating rate was 10°-12°C/minute. The samples were heated from 20°-1100°C, using ignited aluminum oxide as a standard.

Discussion of Results

The thermogram for the Pologi kaolin, shown in Figure 1, indicates that the exothermal effect is much more intense for the sample saturated with H^+ and Ca^{++} ions than for that saturated with Na^+ . The influence of cations on the intensity of the endothermal effect associated with the removal of constitutional water at 540°-585°C, did not manifest itself. These data agree with the data of Caillère and Hénin (9, 12).

There were three endothermal peaks in the low-temperature region at 100°C, 150°, and 275°C in the curves for Ca-kaolin, two at 100°C and 200°C, in the curves for the Na samples, and only one, at 100°C, for the H-samples. The second and third reactions at the higher temperatures are probably associated with the removal of the cation hydration water.

The heating curve for askanite saturated with H^+ (Fig. 2) has four endothermal effects: a double effect with maxima at 150°C and 200°C, a

¹ The samples of L'vov and Kiev clay were kindly given us for investigation by S. V. Potapenko.

² In order to obtain clear changes in thermal effect in the low-temperature region it is recommended that the samples be kept at a relative humidity not lower than 50% (16).

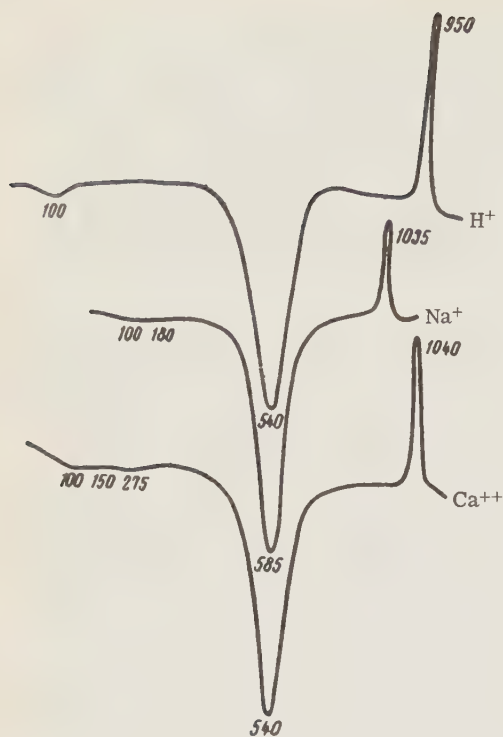


Fig. 1. - Heating curves of Pologi kaolin saturated with various cations (numbers give the temperature, °C).

very weak effect with a maximum at 560°C, then two intense effects at 680°C and 850°C, and one exothermal effect at 975°C. The most intense first endothermal effect consists of two effects, each of which is due to the removal of water ad-

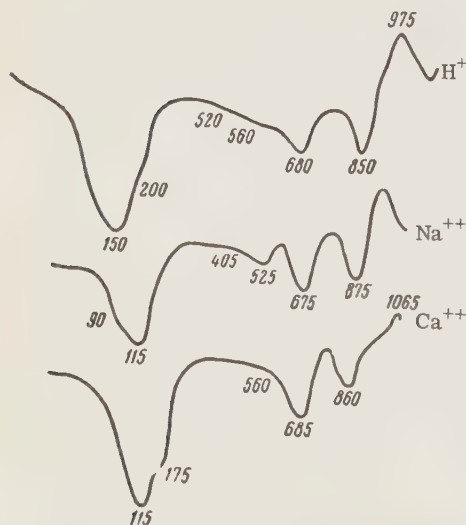


Fig. 2. - Heating curves of askanite saturated with various cations.

sorbed by a bond of varying strength with montmorillonite.

The thermogram for Na-askanite in the high-temperature region is similar to the curve for H-askanite, while the differences in the low-temperature region consist in a decrease of the intensity of the endothermal effect, associated with the removal of adsorbed water, and in the displacement of the maximum toward a lower temperature, 90°C. The removal of constitutional water from Na-montmorillonite begins at 405°C and takes place in two stages, as evidenced by the two endothermal effects with maxima at 525°C and 675°C, which is not usually observed in the heating curves of natural samples and which is very weak in H-montmorillonite. The Na⁺ apparently promotes an earlier dehydration reaction and an earlier decomposition of the lattice, acting as a disperser and mineralizer (1). It must be noted that the Na⁺ did not effect a decrease in the intensity of the endothermal peak at 875°C, even though this effect is almost fully nullified in Na-montmorillonite according to the data of Caillère and Hénin (12).

The curve for Ca-askanite stands out in that

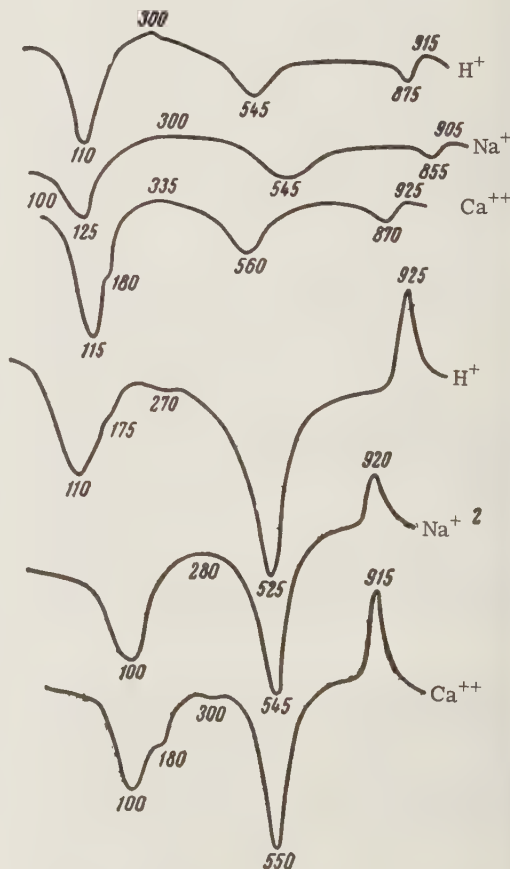
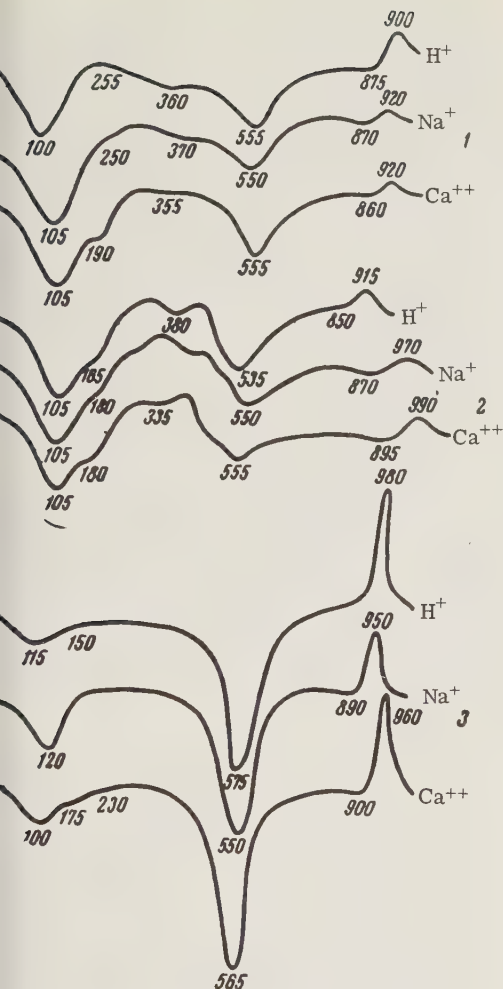


Fig. 3. - Heating curves of L'vov and Kiev clays saturated with various cations. 1 - L'vov clay; 2 - Kiev clay.



4. - Heating curves of the clay fraction of soils saturated with various cations.

1 - chernozem of loess-like clay, Kamennaya loess, Voronezh Oblast'; 2 - chernozem on basalt, Voronezh Oblast'; 3 - chernozem on red Tertiary clay, Voronezh Oblast'.

The second maximum in the low-temperature endothermic effect at 175°C is very pronounced. There is almost no endothermic effect at 525°C. The high-temperature exothermic effect occurs at a higher temperature, at 1065°C, and the curve levels off at the zero level.

Figure 3 shows the thermograms of the 0.01 mm diameter fraction of L'vov clay saturated with H^+ , Na^+ , and Ca^{++} . In comparing three heating curves we notice the following. The intensity of the low-temperature endothermic effect at 110°-115°-125°C is lowest in the curve for the Na-sample, and highest for the H-sample. This effect has a single peak in the case of the H^+ ion and two peaks in the case of Na^+ and Ca^{++} . The lowest maximum for the Na-sample corresponds to a lower temperature,

100°C, and is located on the left branch of the main peak; in the curve for the Ca-sample the lowest maximum is located on the right branch and corresponds to a temperature of 180°C. The form of the high-temperature peaks (endothermic at 545°-560°C, 875°C, 855°C, and 870°C and exothermic at 915°C, 905°C, and 925°C) is more pointed for the H-sample and wider for the Na- and Ca-samples. The intensity of the exothermic effect at 915°C, 905°C, and 925°C is highest for the H-sample and lowest for the Na-sample.

A comparison of the heating curves of Kiev clay saturated with H^+ , Na^+ and Ca^{++} (Fig. 3) shows the differences between the configuration of the low-temperature endothermic peak. The second temperature maximum for the H- and Ca-samples is weakly expressed on the right branch of the peak, while in the case of H^+ and Ca^{++} it is pronounced. The right branch in the curve for the Na-sample is straight while the left is rounded because of the temperature maximum. The endothermic effects associated with the removal of constitutional water did not change under the influence of various cations. The intensity of high-temperature exothermic effects is the same for the H- and Ca-samples (at 925°C and 915°C) and about two times smaller for the Na-sample (at 920°C).

We examined the influence of adsorbed cations on the thermograms of clay minerals having a two-layer, three-layer, and mixed-layer crystal structure and we can make the following conclusions.

Adsorbed cations affect the intensity, temperature, and form (quantity) of thermal effects in heating curves in the low-temperature region (between 20°-300°C) on removal of adsorbed water, on the one hand, and in the high-temperature region (between 850°-1000°C) on the formation of new crystal phases after the composition of the lattice of clay minerals, on the other. Changes in the heating curves in the low-temperature region are important primarily for three-layer, swelling minerals containing a considerable amount of adsorbed (surface and interlayer) water. Changes in the high-temperature region of heating curves are of importance to all clay minerals, independent of their structural characteristics.

The clay samples saturated with H^+ have the most intense low-temperature endothermic effect with a single temperature maximum. The only exception is askanite (montmorillonite clay) in which this effect has three peaks. Na, as a rule, gives a double effect of a lower intensity, whereby the temperature maximum on the left branch of the peak is smaller and very weak, sometimes causing only the rounding of the left branch of the peak. The Ca^{++} increases the intensity of the low-temperature effect, as compared to Na^+ ; the lower maximum is pronounced on the right branch of the peak.

Low-temperature effects are very weak in two-layer kaolinite as a result of the insignificant amount of adsorbed water, even though here also the effect of adsorbed cations on the quantity and nature of water removal is noticeable. In H-kaolinite a large amount of adsorbed water is removed in one stage (at 100°C), in Na-kaolinite it is removed in two stages (at 100°C and 180°C)

and in Ca-kaolinite, in three stages (at 100°C, 150°C, and 275°C).

Adsorbed cations had no noticeable influence on the endothermal reaction to the removal of constitutional water (dehydroxylation effect), which occurred in the temperature interval from 500°-700°C, in clays containing kaolinite. In clays containing three-layer minerals with an expanding lattice (montmorillonite, beidelite) the cations affected the removal rate of hydroxyl water. A splitting of the dehydroxylation effect even occurred in askanite saturated with Na⁺. This may be explained by the fact that the high mobility of the montmorillonite lattice promoted the dispersing effect of the Na⁺. The reaction, which began at a comparatively low temperature of 405°C, ended at about 700°C.³ In H-montmorillonite the dispersing effect of the cation was weak and the removal of constitutional water was more rapid between 520°C and 700°C. The reaction was even faster in Ca-montmorillonite between 560°C and 700°C and there was no splitting of the thermal effect. The same tendency can be seen in the heating curves for L'vov clay containing a montmorillonite mineral, but it is weaker (Fig. 3).

Reactions to the decomposition of the lattice and the formation of new crystal phases from the amorphous products occurs in the high-temperature heating curves of clay minerals between 800° and 1000°C. This is why we observe the same manifestations of the effect of adsorbed cations, independent of the nature of the lattice, namely: H⁺ promotes an increase in the intensity of exothermal effects, while Na⁺ lowers it considerably. The Ca⁺⁺ occupies an intermediate position more close to H⁺. In the case of Na-askanite, a decrease in the temperature of the exothermal reaction is observed, which may be explained by the fact that it begins immediately after the intense endothermal effect at 875°C, while Ca-montmorillonite does not undergo a transition from one reaction to the other.

The influence of alkali on the decrease of high-temperature exothermal effects in the curves of clay minerals is mentioned in the literature. However, it must be noted that ions within the crystal lattice, as in the case of monothermit (1), were considered and not surface-adsorbed cations. Apparently during the heating process after the amorphism of the clay mineral (decomposition of the lattice) and its complete dehydration on further heating, adsorbed cations and the interlattice cations behave in a similar manner.

Let us examine the results of soil investigations. The soil samples studied belong to the same group, chernozem, but these soils developed on different parent materials and under different climatic conditions. The samples included: ordinary chernozem from Kamennaya Steppe, Voronezh Oblast', on loess-like clay deposits; meadow-steppe chernozem

from the Armenian highlands formed on the products of weathering of ultrabasic rocks (basalts, basalt tuff, and volcanic glass) under subalpine climatic conditions;⁴ and southern chernozem (Millerov district, Rostov Oblast') on red Tertiary clay.⁵ According to available data obtained by various methods, the clay fraction of ordinary chernozem from Kamennaya Steppe primarily contains a three-layered mineral with an expanding lattice together with hydromica with an admixture of sesquioxide minerals. The three-layered mineral with an expanding lattice also predominates in the clay fraction of chernozem on basalt, which, however, differs from that in the chernozem from Kamennaya Steppe in that it is greatly enriched with iron, which possibly forms part of the octahed layer, and in that it contains a considerable amount of sesquioxide minerals. Kaolinite, a small amount of the three-layered mineral with the expanding lattice and sesquioxide predominates in the clay fraction of southern chernozem on red Tertiary clay.

As a result of the saturation of the clay fraction of the foregoing chernozem soils with H⁺, Na⁺, and Ca⁺⁺, the following differences in the heating curves were noted: the low-temperature endothermal effect in the curve of the Ca-sample of ordinary chernozem from Kamennaya Steppe (Fig. 4 - 1) exhibits two maxima at 105°C and 190°C, while this effect is singular in the case of H- and Na-samples. The endothermal effect at 900°-920°C is most intense in the H-samples and least in the Na-sample.

The heating curves for chernozem on basalt (Fig. 4 - 2) are distinguished by a great complexity, but the changes as a result of saturation with cations are basically the same as in the chernozem from Kamennaya Steppe; these changes are characteristic for the three-layer expanding mineral. The second maximum in the low-temperature endothermal effect on saturation with H⁺ and Na⁺ (attributable to the incomplete saturation of the samples during preparation for analysis) is most pronounced in the curve of the sample saturated with the Ca ion.

The changes of the low-temperature peak under the influence of various cations in the heating curves of southern chernozem on red clay (Fig. 4 - 3) are of a complicated nature as a result of the presence of a mixture of two clay minerals of varying structure (two-layered and three-layered). There was no change in the mean dehydroxylation effect, the exothermal peaks at 960°-980°C had a similar intensity on saturation with H⁺ and Ca⁺⁺, which decreased noticeably under the influence of Na⁺.

It can be seen from the results of the thermal analysis of the soil samples that changes in heating curves from the influence of adsorbed cations are analogous to the changes in the heating curves of clay minerals in a number of cases, even though the nature of the thermograms is more complicated.

The thermograms of soils saturated with H

³ The end of the thermal reaction occurs, according to observations of V. P. Ivanova, not at the peak of the effect, but somewhat later, on its right branch when the needle returns to the zero position.

⁴ Sample of A. I. Troitskiy.

⁵ Sample of A. P. Shurygin.

ADSORPTION OF CATIONS

ve a smaller number of thermal effects in the low-temperature region and the most pronounced high-temperature exothermal peaks. The intensity of exothermal high-temperature peaks noticeably decreases on saturation with Na^+ . The presence of adsorbed calcium in soils containing three-layered, expanding minerals produces on the heating curves a pronounced second maximum on the right branch of the low-temperature endothermal effect. This allows not only to better define the structural characteristics of the clay mineral, but also to determine the cation saturating the soil when subjecting natural samples (as a whole) to thermography. The high-temperature exothermal effect retains its intensity in the case of the Ca ion in contrast to the heating curves of Na-samples.

Conclusions

1. The study made shows a noticeable effect of adsorbed cations on the nature of heating curves of clay minerals and points to the necessity of taking them into account when determining the mineralogical composition of the clay fraction of clays and soils.
2. The hydrogen ion contributes to the formation of an intense, single (with the exception of montmorillonite) endothermal effect on the thermograms of clays and soils and the most intense exothermal high-temperature peaks.
3. The adsorbed sodium gives a somewhat lesser low-temperature, dehydration effect with a single peak, or with a weak second maximum on the left branch of the peak, and contributes to the decrease in the intensity of high-temperature exothermal effects.
4. The adsorbed calcium causes the splitting of the low-temperature endothermal effect, accompanied by the formation of a pronounced characteristic second maximum on the right branch of the peak at $180^\circ\text{--}190^\circ\text{C}$. This allows to better define the structural characteristics of clay minerals and to determine the cation saturating the soil, or clay, when subjecting the sample as a whole to thermography.
5. Our investigations lead to the conclusion of the necessity of standardizing the preparation of soils for thermal analysis, which must include not only the observance of the same degree of dispersion and moisture content of the samples studied and the removal of organic material from them (8), but also their saturation with one and the same cation.

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COMPARATIVE STUDY OF THE CLAY FRACTION OF TYPICAL SIEROZEM WHEN PREPARING SOIL BY VARIOUS METHODS

PARTICLE-SIZE ANALYSIS

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At the present time N. A. Kachinskiy's method of preparing soils for particle-size analysis with their preliminary treatment with hydrochloric acid and sodium hydroxide is ordinarily used both in the Soviet Union and in people's democracies. Sometimes the method of triturating soil in a pasty state without chemically treating non-carbonate soils is used. The trituration without chemical treatment is unsuitable for soils with a high content of non-silicate iron (yellow earths, red earths, yellow earths-podzolic soils), readily soluble salts, and carbonates.

At the same time triturating soils with a solution of sodium oxalate and a method using sodium hexametaphosphate became widely accepted, for instance in the laboratories of Central Asia. The variety of methods of preparing soils complicates the comparison of data of particle-size analyses. This is why it is necessary to develop a single method of preparing soil for analysis.

In recent years many investigators (7, 10, 3, 1, 8, 12, 14, 11 and others) made comparative studies of various methods of preparing soil for analysis. The methods were evaluated from the degree of dispersion of the soil, i.e., from the quantitative yield of the clay fraction (<0.001 mm diameter) and of physical clay (<0.01 mm diameter), and also from the deviation in the content of other fractions. An examination of the rich material on this problem shows that data obtained by various methods differs not only in the quantitative content of clay, but also in its qualitative composition.

N. A. Kachinskiy (7) points out that the role of separates in the determination of various soil properties depends on their size, form, chemical and mineralogical composition, and also on the stability of the latter in time. From this point of view he divides the separates into three categories: a) ephemeral separates—readily soluble salts, b) calcium, magnesium, and gypsum carbonates—separates intermediate in their stability, and c) the stable silicate, aluminosilicate and ferro-silicate part, as well as the majority of iron and aluminum (R_2O_3) sesquioxides and iron, aluminum, and alkali earth cation humates.

Thus, separates of a given size (for instance, <0.001 mm diameter clay), extracted from one

and the same sample of soils by various methods would differ both in chemical composition and stability. This fact must be taken into account when selecting a method for preparing soil for analysis.

The object of the present study was to determine the differences in the composition of clay removed from the A_1 , B_1 , and B_2 horizon and the underlying material of typical sierozem (Tashkent) with various methods of preparing soil for analysis. The following methods were used in preparing the samples:

- 1) The Kachinskiy method using hydrochloric acid and sodium hydroxide; 2) triturating in a paste state according to the method of Aydynova; 3) triturating in a sodium oxalate solution according to the method of Chernikova; and 4) by using sodium hexametaphosphate according to the method of Bratcheva.

The chemical composition of the initial soil is characterized by the following data. The humus content in the A_1 horizon (0-5 cm) is 2.78%; that in the B_1 horizon (15-50 cm), 0.34%; that in the B_2 horizon, 0.28%; and that in the C horizon, 0.09%. The maximum accumulation of gypsum is found in the underlying material at depth of 15-16 m (0.668%), while in the remaining horizons its content does not exceed 0.2%-0.3%. The amount of carbonate CO_2 in the upper horizon is 6.42% and its maximum content in the B_1 horizon is 11.08%. The dry residue in the water extract does not exceed 0.1%-0.2% in all cases. These data show that the soil investigated is not salinized, but the underlying material at a depth of 15-16 m contains a considerable amount of gypsum.

We used the pipette method in the particle-size analysis with a suspension concentration about 1% and various methods of preparation. Table 1 shows that the clay content obtained by the Kachinskiy method, calculated on carbonate free bases, that obtained by the method of triturating in the paste state, and that obtained by triturating with a sodium oxalate solution did not differ by much in any of the horizons. The yield of clay using the Kachinskiy method was 2%-4% higher than when using the other methods.

In contrast to data in the literature, there was no coagulation when we used the method of triturating in the paste state without chemical

Table 1
Particle-size composition of typical sierozem with various pre-treatment methods for analysis, % of the weight of dry soil

Horizon and depth, cm	Method of preparation	Hygroscopic moisture	Particle density	Pre-treatment with 0.05-N HCl	Diameter of particles					
					1—0.25	0.25—0.05	0.05—0.01	0.01—0.005	0.005—0.001	<0.001
A ₁ 0—5	I	2.51	2.70	16.81	{ 0.68 0.81	{ 4.28 5.12	{ 40.21 48.33	{ 9.83 11.81	{ 10.87 13.06	{ 17.34 ^a 20.84 ^b
	II	—	—	—	0.74	7.41	48.89	11.27	15.66	{ 38.04 45.74
	III	—	—	—	0.63	7.45	50.34	8.27	44.51	{ 16.57 18.82
	IV	—	—	—	1.79	10.64	49.52	12.89	14.30	{ 41.59 38.01
B ₁ 15—50	I	2.57	2.53	22.30	{ 0.04 0.05	{ 5.04 6.52	{ 36.17 46.55	{ 9.62 12.37	{ 9.12 11.73	{ 17.71 22.78
	II	—	—	—	0.02	6.49	45.18	12.14	15.85	{ 36.76 46.88
	III	—	—	—	0.04	9.68	42.43	12.28	16.27	{ 20.21 19.26
	IV	—	—	—	0.48	9.48	45.43	13.58	16.10	{ 47.80 44.61
B ₂ 50—100	I	2.60	2.47	26.30	{ 0.03 0.04	{ 4.38 5.95	{ 35.82 48.60	{ 9.8 13.37	{ 7.9 10.81	{ 15.7 21.23
	II	—	—	—	0.04	6.35	44.93	11.87	15.74	{ 33.5 45.41
	III	—	—	—	0.02	6.21	45.89	13.06	15.33	{ 21.07 18.97
	IV	—	—	—	0.47	8.55	47.59	13.51	15.91	{ 47.35 43.40
15—16 M	I	2.65	2.52	22.42	{ 0.03 0.04	{ 5.09 6.57	{ 41.95 54.07	{ 9.09 11.71	{ 7.39 9.52	{ 14.04 18.09
	II	—	—	—	0.02	5.10	62.00	27.06	3.99	{ 30.52 39.32
	III	—	—	—	0.01	5.00	52.42	12.94	11.81	{ 1.58 ^c 17.83
	IV	—	—	—	0.16	7.46	57.98	12.50	11.15	{ 42.57 34.41

^aFor the entire sample, including losses from 0.05-N HCl.
^bFor the carbonate-free sample.
^cCoagulation.
 Note: Methods: I—of N. A. Kachinskiy; II—soil triturating; III—same, using a sodium oxalate solution; IV—using sodium hexametaphosphate.
 Note: Comma represents decimal point.

Table 2

Total chemical analysis of clay fractions (<0.001 mm diameter), extracted from typical sierozem using various methods of preparation,
% of ignited sample

Horizon and depth, cm	Method of preparation	Hygroscopic moisture	Loss on ignition		SiO ₂	R ₂ O ₃	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	P ₂ O ₅	SiO ₂ — R ₂ O ₃
			Humus	in percent								
A ₁ 0—5 B ₁ 15—50 B ₂ 50—100 1500—1600	Kachinskiy's method by treating soil with 0.05-N HCl and 1-N NaOH (I)	6, 10 7, 08 8, 03 8, 25	3, 10 1, 99 0, 67 1, 22	9, 22 8, 07 8, 37 7, 78	55, 18 ^a 55, 63 55, 38 56, 82	35, 44 34, 54 33, 73 31, 35	12, 22 11, 18 11, 16 11, 45	23, 00 23, 36 22, 57 22, 90	0, 55 0, 65 0, 45 0, 55	5, 02 5, 10 5, 76 5, 79	0, 10 0, 09 0, 08 0, 08	3, 47 3, 20 3, 20 3, 24
A ₁ 0—5 B ₁ 15—50 B ₂ 50—100 1500—1600	Triturating in the paste state without chemical treatment (II)	6, 50 7, 57 7, 91	5, 20 1, 95 0, 63	13, 32 10, 41 10, 96	55, 70 52, 00 52, 82	35, 89 33, 52 33, 63	11, 43 10, 09 10, 61	24, 76 23, 43 23, 02	1, 82 4, 30 5, 00	5, 40 5, 36 5, 68	0, 38 0, 25 0, 11	2, 96 2, 97 3, 10 —
A ₁ 0—5 B ₁ 15—50 B ₂ 50—100 1500—1600	Triturating with a Na ₂ C ₂ O ₄ solution (III)	6, 36 6, 78 7, 13 7, 81	5, 03 1, 76 0, 86 0, 79	13, 05 11, 95 12, 97 10, 23	54, 41 52, 18 51, 77 54, 45	34, 34 32, 72 32, 01 33, 43	10, 86 10, 08 9, 91 10, 48	23, 48 22, 64 22, 10 22, 65	3, 47 7, 39 9, 12 4, 86	5, 43 5, 47 5, 43 5, 98	0, 32 0, 24 0, 13 0, 12	3, 10 3, 07 3, 44 3, 21
A ₁ 0—5 B ₁ 15—50 B ₂ 50—100 1500—1600	Using (NaPO ₃) ₆ (IV)	6, 52 6, 83 7, 50 8, 17	7, 30 2, 28 1, 55 1, 46	14, 86 12, 45 10, 75 9, 83	53, 77 56, 56 54, 19 54, 37	34, 06 32, 24 30, 72 32, 99	10, 39 10, 01 9, 79 10, 51	23, 67 22, 33 20, 93 22, 48	3, 42 8, 42 7, 91 4, 03	4, 98 5, 13 5, 33 5, 78	1, 35 1, 83 1, 72 1, 12	3, 17 3, 00 3, 27 3, 21

^aData obtained from two measurements.

Note: Comma represents decimal point.

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atment of carbonate soil (A_1, B_1, B_2 horizons), except for the underlying material (15-16 m). The results of analysis by this method are similar to data obtained by the Kachinskiy method. This is probably related to the fact that calcium in sierozems occurs primarily in two states: a small part of it is in the adsorption complex, while its bulk is in the form of calcium carbonate. The small amount of calcium carbonate as CO_2 solution is only slightly soluble in water. Being mechanically pulverized by triturating it forms a stable dispersion in water and at the same time does not produce flocculation of colloids because of the electrical neutrality of the $CaCO_3$ molecule. Flocculation increases in the underlying material because of the presence of gypsum (368%), which is highly soluble (0.2%). This is also promoted by readily soluble salts in the horizon.

The method of triturating soil with sodium carbonate yielded 2%-4% less clay than the method of Kachinskiy. It must be remembered that when this solution is added to the suspension, insoluble salt forms (CaC_2O_4) which distorts particle-size analysis when it becomes part of the clay fraction.

The yield of clay is considerably smaller when the method using a sodium hexametaphosphate dispersion than it is for the foregoing methods. This is related to the formation of non-dissociating complexes, or films (calcium-magnesium-sodium metaphosphate), when the dispersing agent comes into contact with calcium and calcium carbonate ions. The film only surrounds the carbonate particles and prevents their peptization, and the flocculation of various colloidal systems, but also coats soil microaggregates and prevents their dispersion.

In preparing sierozem for the extraction of the clay fraction for its chemical and mineralogical analysis, the same methods were used for the particle-size analysis.

Hundred grams of soil sieved through 1 mm openings were treated correspondingly and placed in a 6-liter vessel. After letting it set for one day, the clay fraction was siphoned. The falling velocity of the particles was calculated using Stokes' formula. The decanted dispersion was filtered in Buchner funnels with a water pump. The obtained fractions were dried (the open) until air-dry, ground with a pestle in a rubber head, and put through a sieve with 0.1 mm openings. Then the total chemical and thermal analyses were made.

Humus was determined in the chemical analysis by the Tyurin method; iron and aluminum oxides (R_2O_3), and calcium and magnesium oxides were determined by methods described in the work of Arinushkina (2); and phosphoric acid was determined electrocolorimetrically. Thermal analysis was made on the Kurnakov calorimeter (FPK-55) with a platinum-platinum-chromium thermocouple (3 g samples) without previously igniting the organic material of the sample. The heating rate was $10^\circ C$ /minute. The results of the total chemical analysis are given in Table 2. The hygroscopic moisture of the clay fraction in all cases gradually increased in the deep horizons, which is probably due to the

content of colloidal particles (<0.0001 mm diameter) in the clay of these horizons. The hygroscopicity of clay was approximately the same for all the separation methods used.

The humus content was highest in the clay fraction of the upper horizon (A_1) and decreased greatly in the lower horizons. This agrees with the change in the humus content of the initial soil. A lower humus content was obtained for the clay fraction of the A_1 horizon, obtained by the Kachinskiy method than when other methods were used. This is attributable to the fact that when sodium hydroxide is added as a dispersing agent, part of the humus goes into solution. When this solution is siphoned in Buchner funnels, the dissolved humus is in the filtrate. However, there is no such loss during particle-size analysis by Kachinskiy's method, since during the separation of the clay fraction with a pipette when evaporating, the dissolved humus enters this fraction.

The increase in the humus content of the clay fraction in all horizons, obtained by the method using sodium hexametaphosphate, is conspicuous. This increase reaches 2% in the A_1 horizon and 1% in the lower horizons. In this method the loss of humus when siphoning the filtrate in Buchner funnels is minimal, since it is protected from dissolution by "protective films" of double salts, such as for instance $Na_2Ca_2(PO_3)_6$.

A partial loss of humus on siphoning the filtrate in Buchner funnels occurs with the II and III method of preparing soil samples for analysis, as with the Kachinskiy method, but it is smaller than when method I is used.

The ignition loss (Table 2) in all samples prepared by the various methods decreases with depth along the soil profile. It varies from 9.22%-7.78% in method I; from 13.32%-10.96%, and from 13.05%-10.23% in methods II and III; and from 14.86%-9.83% in method IV. The highest ignition loss occurs in the clay of the upper horizons, which is associated with their high humus content. When methods II, III, and IV of preparing soil are used, the ignition loss in clay fraction in the lower horizons (B_1, B_2 , and underlying material) is 2%-4% higher than when the Kachinskiy method is used. This is due to the presence of carbonates, gypsum, and a certain amount of soluble salts in the clays obtained by these methods. The ignition loss of clays obtained by methods II, III, and IV increases as compared to the loss of clay obtained by the Kachinskiy method as a result of the loss of CO_2 carbonates and of the crystallization water of salts.

The divergence in the silicic acid content of the clay fraction removed from various horizons by the Kachinskiy method does not exceed 1%-2% and the variation in the Fe_2O_3 and Al_2O_3 contents is not more than 1%. In comparing the Kachinskiy method with other methods (II, III, and IV) it must be noted that: 1) the clay fraction obtained by the Kachinskiy method contains more SiO_2 and R_2O_3 , as compared to the other methods, it is more aluminous- and ferro-silicate, so to speak; 2) it is more stable in composition, especially as compared to clay removed by methods III and IV; 3) the greatest difference between the clays removed by the various methods is in their

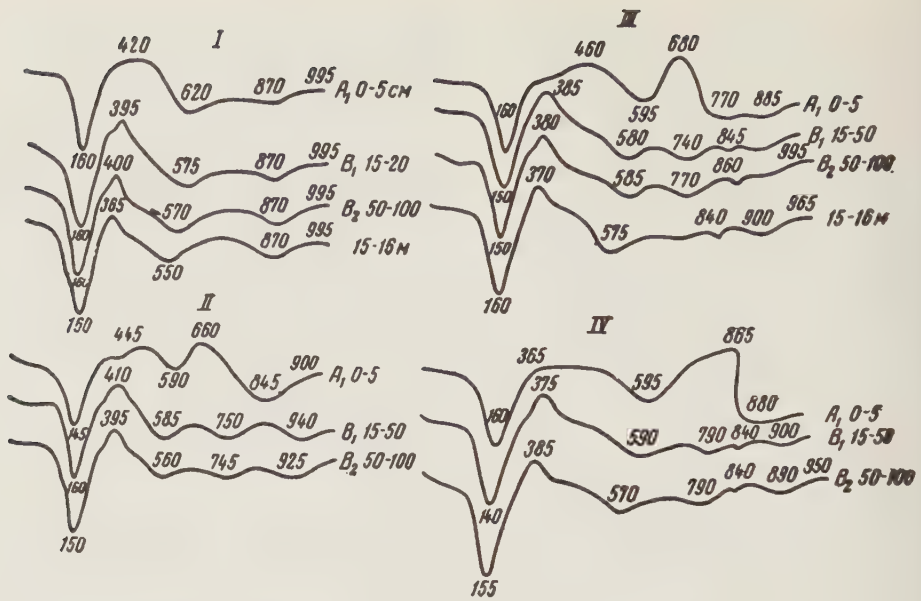


Fig. 1. - Thermograms of the clay fraction of typical sierozem under various methods of preparation for particle-size analysis.

Methods: I-Kachinskiy; II-triturating soil in the paste state without chemical treatment; III-triturating soil with a sodium oxalate solution; IV-method using sodium hexametaphosphate.

CaO and P_2O_5 contents. The lowest calcium oxide content is found in the clay fraction obtained by the Kachinskiy method. The CaO is naturally much higher in the clay obtained by triturating the soil in the paste state. The maximum accumulation of calcium oxide is found in the clay obtained by triturating with a solution of sodium oxalate and sodium hexametaphosphate. It is 18 times higher than the CaO content in clay obtained by the Kachinskiy method and 80 times higher than in clay obtained by grinding without the removal of carbonates (II). This is due not only to the retention of carbonates and gypsum in clay obtained by methods III and IV, but also to the accumulation of clay in new products (CaC_2O_4 and $Ca_3P_6O_{18}$) formed when $Na_2C_2O_4$ and $(NaPO_3)_6$ interact with calcium contained in the adsorption complex and in individual minerals.

The amount of magnesium oxide is approximately the same along the soil profile with all methods of preparation. Magnesium apparently occurs in sierozems primarily in the form of magnesium minerals which are very stable.

The data show that the phosphoric acid content in sierozem varies little along the soil profile; it is slightly higher in the upper horizon than in the lower ones, which is associated with the presence of humus in it.

Phosphoric acid in the clay fraction of sierozem is most accurately reflected by the method of triturating soil without chemical treatment, since in this case it is not artificially added and removed from the soil.

The smallest amount of P_2O_5 was found in the clay obtained by the Kachinskiy method, since part of it is lost with the soluble humus on siphoning the filtrate in Buchner funnels. As mentioned earlier, this loss does not take place in particle-size analysis according to the method. A sharp increase (several times) in the amount of P_2O_5 was found in clay obtained by the method of Bratcheva, since in this method P_2O_5 is added into the soil by the reagent ($Na_6P_6O_{18}$) itself.

To determine the mineralogical composition of the clay fraction obtained by various methods of soil preparation, we subjected it to thermogravimetric analysis. The thermograms (Fig. 1) of the clay fraction obtained by the Kachinskiy method show that the same mineral predominates in all the genetic horizons of the soil investigated. There are endothermal effects on the thermogram at all the horizons at $160^\circ C$, $550^\circ-600^\circ C$ and $875^\circ C$, and exothermal effects at $365^\circ-420^\circ$ and $995^\circ C$. The first endothermal effect at $160^\circ C$ indicates the presence of a large amount of sorbed water. The second, at $550^\circ-600^\circ C$, corresponds to the removal of constitutional water present in the crystal lattice of the minerals studied. The third is associated with the first decomposition of the crystal lattice of the mineral. The first exothermal effect at $365^\circ-420^\circ C$ is the result of the combustion of organic material (6). On the basis of the foregoing effects on the thermogram and data on the molar ratio of $SiO_2:R_2O_3$ from the total chemical analysis (3.17-3.24) one may state that the predominant mineral in the clay fraction of the sierozem studied is hydromica. Rozanov also menti-

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presence of this mineral in the sierozem of Central Asia (13).

The thermograms of the clay fractions obtained by the other methods gave a very complicated and unruly picture. But, in comparing these thermograms with those of the clay fraction obtained by the Kachinskiy method, it is clear that they also have three main endothermal effects: at 145°-150°C, 560°-590°C, and 745°-845°C in the clay fraction obtained by trituration in paste state without the removal of carbonates; and at 140°-160°C, 570°-595°C, and 740°-790°C in the clay fraction obtained by trituration of the soil with a solution of sodium oxalate and by the method using sodium hexametaphosphate. However, the combustion of organic material greatly interferes with the clarity of these effects on all thermograms of the clay fraction of the upper horizon (0-5 cm) obtained by these methods.

There are another two endothermal effects at 800°-1000°C in the thermograms of the clay fractions from the lower horizons, obtained by methods II, III, and IV, because of the presence of a large amount of carbonates, especially calcium carbonate, which are probably associated with the thermal effect of CaCO_3 (15). Taking into account the molecular ratio of $\text{SiO}_2:\text{R}_2\text{O}_3$ (2.96-3.44) in the fractions obtained by the last three methods, one may assume on the basis of all these thermal effects that the predominating clay mineral in these fractions is also hydromica, but it contains a larger amount of carbonates.

Conclusions

1. The various methods of preparing soils for particle-size analysis disperse the soil differently. The yield of clay is highest when the Kachinskiy method is used and least in the method using sodium hexametaphosphate. The methods of trituration with a $\text{Na}_2\text{C}_2\text{O}_4$ solution and trituration in the paste state without chemical treatment gave the least reliable and least stable results. The method of trituration in the paste state is unsuitable for the preparation of soils which contain gypsum and easily soluble salts. The dispersion prepared by this method flocculates in the presence of calcium bicarbonates and of a large amount of mobile forms of iron and aluminum in the foregoing compounds.

2. The qualitative composition of clay obtained from the various methods of preparing soil for analysis differs: a) the most stable silicate and alumino- and ferro-silicate parts predominate in the fraction obtained by the Kachinskiy method; b) clay obtained by the method using sodium hexametaphosphate and the method using sodium oxalate contains not only carbonates, but also newly formed products ($\text{Ca}_3\text{P}_6\text{O}_{18}$ and CaC_2O_4).

3. The predominating clay mineral in the chernozem studied is hydromica, as evidenced by the thermal analysis of clay obtained by the Kachinskiy method. This mineral is less pronounced in clay obtained by the other methods.

4. The separation of the clay fraction for total chemical and mineralogical analyses by

filtration of the clay suspension and dispersion with sodium hydroxide in Buchner funnels leads to a partial loss of soluble humus, and part of the silicic and phosphoric acids. In order to eliminate this shortcoming in the analysis, the filtrate must be evaporated, or the foregoing components in it must be determined.

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APPARATUS FOR MASS PARTICLE-SIZE ANALYSIS OF SOILS

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The method ordinarily used in the particle-size analysis of soils is the pipette method which consists, as we know, in taking samples of a suspension, prepared by various methods with a special pipette at definite time intervals, established by Stokes' formula, and drying and weighing them. The separates to be studied are determined from the differences between the weights of the samples taken, relative to the entire volume of the suspension and to the weight of soil samples taken.

When investigating soils and soil materials the content of the following separates is usually determined: >1 mm; 1-0.25 mm; 0.25-0.05 mm; 0.05-0.01 mm; 0.01-0.005 mm; 0.005-0.001 mm; and <0.001 mm. The first two are determined with the aid of sieves, the last four, by the pipette method, and the third, by difference. In determining the last four, samples are taken of summation fractions with the following diameters: Fraction I, <0.05 mm; fraction II, <0.01 mm; fraction III, <0.005 mm; and fraction IV, <0.001 mm.

The volume of the pipette for taking samples is usually 20 ml or 25 ml. Ten grams of soil are taken for analysis and after appropriate preparation the suspension is brought to 1 liter.

The main shortcomings of the pipette method are: 1) the small volume of the pipette, the sample taken being only 2%-2.5% of the total volume of the suspension. When one considers that the concentration of the suspension is only 1%, then it is clear that the slightest fluctuation in the weights of the precipitate, independent of particle size, may lead to a considerable distortion of the results of the analysis. 2) The necessity of accurately maintaining a constant temperature during the whole period of analysis, since the specific gravity of water and its viscosity, which depend on temperature, are involved in Stokes' formula. However, it is often very difficult and sometimes impossible to fulfill this requirement. 3) The necessity to immerse the pipette to the required depth into the suspension when drawing each sample and then remove it in order to transfer the sample to the drying dish. Such manipulations, no matter how carefully done, disturb the sedimentation of particles and may lead to inaccurate results. Other difficulties of the pipette method in particle-size analysis are mentioned in the work of Dolgova and Zhitkova (1).

Because of the conduct of detailed soil investigations by kolkhozes in our country, the necessity arose for mass particle-size analyses of soils. For this purpose we propose a device which eliminates the foregoing shortcomings and allows one to make 10 analyses simultaneously. In addition we tried to construct an instrument of such materials which would be available to laboratories of experimental stations, regional agricultural chemical laboratories, etc. Below we give the description of the individual parts of the device and their construction.

The device for mass soil particle-size analyses designed by us consists of a suspended wooden holder with 10 partitions in which sedimentation glass cylinders are placed. The bottoms of the cylinders are provided with tubes through which discharge valves and stirrers for stirring the suspension in the cylinders are inserted (Fig. 1).

In order to take samples it is necessary to have 40 porcelain cups, or large crucibles, of 90-100 ml capacity and a table clock with a second indicator. An ordinary holder with two rings with sleeves is used for placing a cylinder when the prepared sample is transferred into it.

The suspended holder, built of boards 20 mm thick, is a box having the following inner dimensions: a length of 765 mm, a height of 380 mm, and a depth of 70 mm. The bottom of the box is cut out so as to receive the cylinders and is provided with dividers at the top for separating the cylinders and holding them in an upright and stable position with the aid of a wire (Fig. 2). The box is provided with two front doors (hinged on the side) and a common lid which is hinged to the back wall of the box (not shown in the figure). The doors and lid are held by hooks when closed. The box is lined with cloth, or thin felt, to insure that continuous proper temperature is maintained during the sedimentation.

Sedimentation cylinders. "Syrup jars," which are available in grocery stores and have a tube at the bottom, are used as sedimentation cylinders (Fig. 3). The length of the cylindrical portion of these containers is about 37 cm. Their internal diameter averages 55.5 mm. Assuming that the volume of the decanted sample of the suspension is 75 ml, the layer of the decanted suspension in a cylinder of the foregoing diameter is 31 mm thick. On the basis of this, the cylinders are marked in the following way. A line is drawn

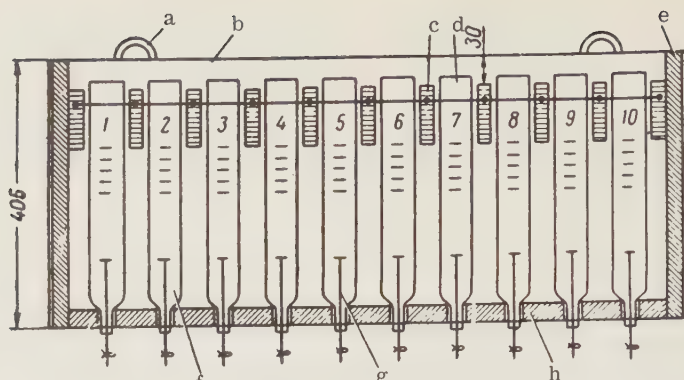


Fig. 1. - General view of the apparatus

a - ear; b - back wall; c - divider; d - wire; e - side wall; f - sedimentation cylinder; g - discharge valve; h - bottom with cuts.
1 - 10 - cylinder numbers.

(with a file, or with indelible paint) on the wall of the cylinder at a distance of about 6 cm from the bottom (this distance is measured approximately; it is desirable that this line be on the same level when the cylinders are placed in the holder—it has no importance for the measurements, but the apparatus looks better). Then another line is drawn above the first at a distance of 20 cm, and then four more lines are drawn at a distance of 31 mm from the upper line and from each other. Each cylinder is provided with a rubber stopper through which a hole is made with a corkscrew of such a diameter that the tube of the drainage valve would tightly fit in it. The stopper with the drainage valve must be inserted from the inside of the cylinder for which a wooden rod must be used with which to press carefully and gradually the stopper into place. Finally, the tube at the bottom of the cylinder must be cut in advance so that it is about 1 cm long.

way. An automobile fuel, or oil pipe (the outside diameter of such a pipe is about 6 mm, and its internal diameter, about 4.5 mm), is cut into pieces 9 cm long and sharpened at the end to a cone (Fig. 4). Then, pieces 11 cm long are cut from bicycle spokes; these pieces have a ready thread at one side and must be provided with a 2.3-mm thread 1 cm long on the other. Further, the upper parts of the heads of the bicycle spokes are cut with a hand saw to serve as nuts, and four longitudinal grooves are made with a file on the rounded ends of the remaining parts to serve as guides. Next, small circles about 8 mm in diameter are cut from the inner tube of an automobile tire to serve as valves. Springs in the form shown in full scale in Figure 4 are made from an iron wire (preferably containing steel) about 1 mm in diameter. The inside and outside of the drainage tube, as well as all the other components of the valve, must be coated with nitro lacquer, or better, be nickel-plated.

Drainage valves are made in the following

The drainage valve is mounted in the following

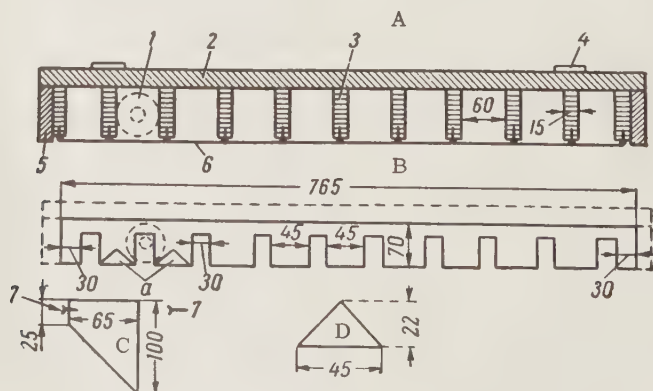


Fig. 2. - Arrangement of dividers and of the wire holding the cylinders: A - (top view) Bottom of the suspended holder, B - Divider, C - Detail "a", D - is attached to all the projections of the bottom for holding the cylinders in place (5 mm thick). 1 - cylinder; 2 - back wall; 3 - dividers; 4 - ear; 5 - side wall; 6 - wire; 7 - place where wire is attached (15 mm thick).

APPARATUS FOR MASS PARTICLE-SIZE ANALYSIS

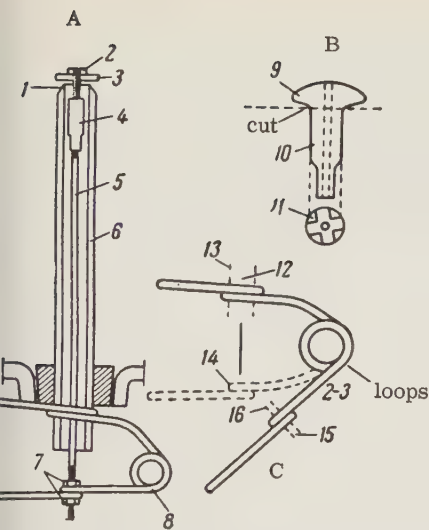


Fig. 3. - Decanting cylinder with graduations A, and stirrer for muddying the suspension -B

a - drainage valve; b - rubber stopper; c - spring; d - nut; e - rubber circle.

First the drainage tube must be inserted into the stopper in such a manner that the top end of the tube is exactly at the level of the lowest graduation on the cylinder after it has been properly inserted in the cylinder tube (from inside the cylinder). Then, the rod of the valve must be assembled: first, the guide is screwed onto one end of the piece of bicycle spoke and then the rubber circle is put on (after a hole has been made in it with a pin) and fastened with the nut. Then, the assembled valve rod is inserted in the drainage tube (from inside the cylinder), the rubber stopper is mounted on the tube, the valve rod is pushed through the spring, and the spring is compressed in a stretched position by two nuts as shown in Figure 4.

The stirrer for stirring the suspension is shown in Figure 3. It consists of a rubber circle 4-5 mm thick and of such a diameter that

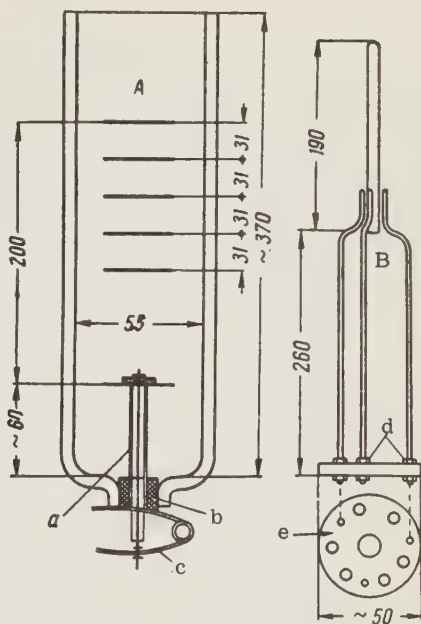


Fig. 4. - Drainage valve - A, and its details, B and C.

1 - sharpened end of the tube; 2 - nut; 3 - rubber circle 8 mm in diameter; 4 - guide; 5 - valve rod (length 110 mm); 6 - valve tube (length 90 mm, outer diam, 6 mm, inner diam, 4.5 mm); 7 - nut; 8 - spring. B - head of a bicycle spoke; 9 - nuts; 10 - adjuster; 11 - longitudinal groove along the rounded portion. C - spring; 12 - diameter of the opening along the tube of the valve; 13 - valve tube; 14 - spring when compressed, the centers of both openings are above each other; 15 - diameter of the opening is slightly larger than the thickness of the rod; 16 - rod.

it can be freely, but not loosely, inserted into all the cylinders of the device. Three bicycle spokes are driven through the circle and fastened on both sides by nuts, soldered to the handle. The circle has a hole 15-20 mm in

Table 1

Determination of the design depth for taking samples

Fraction		Thickness of the decanted layer, cm(h)	h/2	Depth from which the sample is taken	Calculated depth for taking sample
No.	Diameter			in cm	
I	<0,05	3,1	1,55	— — 20,0	20,0—1,55=18,45
II	<0,01	3,1	1,55	20,0—3,1=16,9	16,9—1,55=15,35
III	<0,005	3,1	1,55	16,9—3,1=13,8	13,8—1,55=12,25
IV	<0,001	3,1	1,55	13,8—3,1=10,7	10,7—1,55=9,15

Note: Comma represents decimal point.

Table 2

Form for recording analytical results

Laboratory Number of the sample	Cylinder Number	Index of jar	Weight of the empty jar	Weight of jar with dry sam- ple	Weight of the dry sample	Coefficient (K)	Summation of fractions in %	Separates	
				in g				in mm	in %
I	I	I	...	...	...	$K_I = \dots$	1 = ...	0,05—0,01	(1—2).
		I	...	...	...	$K_{II} = \dots$	2 = ...	0,01—0,005	(2—3).
		II	...	...	...	$K_{III} = \dots$	3 = ...	0,005—0,001	(3—4).
		I	...	...	...	$K_{IV} = \dots$	4 = ...	<0,001	(4)...
		III	...	...	...				
		I	...	...	...				
		IV	...	...	...				
		2	...	...	...	$K_I = \dots$	1 = ...	0,05—0,01	(1—2).
		I	...	...	...	$K_{II} = \dots$	2 = ...	0,01—0,005	(2—3).
		2	...	...	...				
		II	...	...	...				

Note: Comma represents decimal point.

diameter in the center and six peripheral holes 5-6 mm in diameter. This stirrer can be used to stir the suspension in the cylinders without fear of disturbing the drainage valves.

One may see from the description of the apparatus that the role of pipette for drawing samples is played here by the drainage valve which is installed at a constant depth. The first sample is taken from the depth at which the valve is located, that is 20 cm; each following sample is taken from a depth which decreases by the amount of the sample taken, i.e., by 31 mm each time. This is the way in which the actual depth at which samples are taken is determined; the calculated depth, however, is determined proceeding from the necessity of immersing the pipette deeper each time to half

the depth of the layer sampled (I). All the calculations are shown in Table 1.

It takes about 10 seconds to draw one sample by means of the drainage valve so that the first sample (the coarsest fraction) must be taken from each cylinder half the time (5 seconds earlier than the calculated time for the fall particles to the given depth (2).

The following must yet be mentioned. The "syrup jars" used in the device rarely have diameter of exactly 55.5 mm, it usually fluctuates around this value; and this is why it is necessary to calibrate each cylinder. To do this, a completely mounted cylinder is filled with distilled water to the upper line and its amount is measured. The volume obtained

Table 3

Time intervals between the drawing of samples

Temperature, °C	Fractions of diameters (mm)					
	I <0,05	II <0,01	III <0,005		IV <0,001	
	seconds	minutes	hours	minutes	hours	minutes
16	91	32	1	41	31	25
18	87	30	1	36	29	56
20	83	29	1	31	28	28

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Table 4
Working table for drawing the samples

Cylinders	1	2	3	4	5	6	7	8	9	10
Initial arrangement	9.00	9.03	9.06	9.09	9.12	9.15	9.18	9.21	9.24	9.27
Fraction I	Fraction I is drawn from each cylinder 78 sec after it has been stirred									
Fraction II	9.29	9.32	9.35	9.38	9.41	9.44	9.47	9.50	9.53	9.56
Fraction III	10.31	10.34	10.37	10.40	10.43	10.46	10.49	10.52	10.55	10.58
	On the next day									
Fraction IV	13.28	13.31	13.34	13.37	13.40	13.43	13.46	13.49	13.52	13.55

Note: The time of withdrawing fraction I is reduced by 5 sec.

written down and is the total volume of the suspension in the given cylinder. Then the valve is opened and the water is drained to the second line into a graduated 100-ml cylinder; this is the volume of the first sample. The same procedure is followed from the second to the third line, etc. All the volumes are recorded. Let us assume that the total volume of water (A) in the first cylinder is 590 ml, while the volume of the samples (B) is: I-72 ml; II-76 ml; III-74 ml; and IV-75 ml; then the coefficients (K) for calculating the percentages of summation fractions for the given cylinder are found from the formula: $K = \frac{A \cdot 100}{B - 10}$, where 10 is the soil sample and 100 is the conversion into percents. From this the coefficients for the samples in our example will be: $K_I=82.0$; $K_{II}=77.6$; $K_{III}=79.7$; and $K_{IV}=78.3$. The coefficients are determined in the same manner for all the cylinders and a

table is compiled which is fastened to the door of the apparatus.

Instead of the porcelain cups we used porcelain jars of a capacity of about 90 ml. Each was given a number showing the number of the cylinder (in the numerator) and the number of the sample (in the denominator), thus:

$\frac{I}{I}, \frac{I}{II}, \frac{I}{III}, \frac{I}{IV}, \frac{2}{I}, \frac{2}{II}$ etc. All the jars were

placed in a common box to form ten rows (corresponding to ten cylinders) with four jars in a row (corresponding to four samples); such an arrangement facilitates the correct selection of the samples.

Particle-size analysis with the foregoing apparatus is simple and easy and consists of the following. A 10-gm soil sample (air-dried) is

Table 5
Data of comparative analyses of sod-podzolic, fine clay loam made by various methods, %

Replication	Particle diameter (mm)							
	0,05—0,01		0,01—0,005		0,005—0,001		<0,001	
	pipette method	Kuchinskiy's method	pipette method	Kuchinskiy's method	pipette method	Kuchinskiy's method	pipette method	Kuchinskiy's method
1	40,8	43,3	10,4	8,7	9,1	9,2	32,6	30,2
2	44,2	42,2	8,1	8,7	9,6	9,1	30,2	30,6
3	39,3	43,9	6,8	8,5	8,1	9,7	34,9	30,2
4	45,1	42,3	7,5	9,4	7,2	9,4	29,9	31,2
5	41,6	42,3	6,6	7,8	8,2	10,1	31,2	30,2
6	40,6	44,2	6,9	9,4	11,0	9,4	30,6	30,9
7	42,7	42,3	9,4	8,8	8,8	9,6	31,2	30,5
8	46,2	43,9	6,9	9,4	10,7	9,7	28,9	30,9
9	43,7	42,3	6,5	8,8	10,4	9,4	26,6	30,9
10	40,4	41,6	10,3	8,4	8,1	9,4	31,2	30,9
Average	42,4	42,8	7,9	8,8	9,1	9,5	30,7	30,7

Note: Comma represents decimal point.

Table 6

Comparisons of particle-size analyses of the plowed layers of various soils by various methods, %

Inventory Number of the UNILza	Method	Particle diameter, mm						
		>0,25	0,25—0,05	0,05—0,01	Total <0,01	0,01—0,005	0,005—0,001	<0,001
1136	Pipette	0,2	11,9	62,5	24,4	6,5	6,1	11,8
	Kuchinskiy's	0,1	9,9	63,6	23,1	5,6	6,6	12,9
1687	Pipette	23,0	43,9	17,6	14,2	2,9	3,2	8,1
	Kuchinskiy's	23,0	40,0	20,3	15,0	3,3	3,1	8,6
1692	Pipette	37,4	51,8	5,7	4,8	0,3	1,2	3,3
	Kuchinskiy's	35,2	50,2	9,5	4,7	0,6	1,7	2,4
1696	Pipette	20,9	32,9	25,1	20,2	5,1	7,4	7,7
	Kuchinskiy's	19,5	30,4	28,2	21,1	6,0	7,4	7,7
1709	Pipette	30,8	35,2	21,3	10,5	1,8	2,8	5,9
	Kuchinskiy's	27,8	35,1	24,0	11,6	1,7	3,6	6,3
1747	Pipette	19,7	29,4	27,6	22,6	6,3	7,1	9,2
	Kuchinskiy's	19,5	26,5	29,4	23,2	6,2	7,4	9,6

Note: Soil sample of 10 gm, prepared according to the method of M. M. Godlin.

Note: Comma represents decimal point.

sieved through a 0.25 mm diameter opening sieve into a sedimentation cylinder which is filled with liquid to the upper line. Then the suspension is stirred with the stirrer and samples are withdrawn into porcelain jars at definite time intervals by pressing on the spring of the valve. The drawing of the first three fractions from the ten cylinders takes about two hours with the doors of the apparatus being open. Then the apparatus is closed until the last sample is taken, which is done the next day (see below). The contents of the jars are evaporated on a water bath, and dried in a drying cabinet. All weighing is done on an industrial balance (200 g) with an accuracy of up to 0.01 g. The results are recorded on a form prepared beforehand (Table 2).

Assuming for mass analyses that the specific gravity of the soil is 2.65 and that the falling heights are such as shown in the last column of Table 1, we obtain the time intervals for drawing samples from the suspension (Table 3).

Since the apparatus is designed for conducting ten analyses simultaneously, it is very important to plan the work properly. It is best to complete the preparation of the samples in time to transfer them into the cylinders at the end of the working day; then the drawing of the samples can begin at 9 a.m. the following morning. As an example we prepared a working table at a temperature of 20°C (Table 4).

The suspension in cylinder No. 1 is stirred one minute before 9 a.m. Since settling occurs during the night at the bottom of the cylinder, it is necessary to stir it strongly to lift it fully from the bottom and then evenly mix the suspension. Mixing is done rapidly by lowering the stirrer to the bottom and lifting it to the surface of the liquid, taking care that no air bubbles form. The stirrer must be lifted and lowered the same number of times in all cylinders within a definite time interval, for instance, 30 times in 60 seconds, etc.

The time interval between the stirring of the suspension in the cylinders is 3 minutes. Thus stirring cylinder No. 1 is finished by 9 a.m., the stirrer is removed, and 78 seconds later fraction I is drawn from it into the corresponding jar. Then at 9:02 a.m. the suspension in cylinder No. 2 is stirred until 9:03 a.m., and 78 seconds later fraction I is drawn and so on until cylinder No. 10 is processed. After fraction I is drawn from cylinder No. 10, the time comes to draw fraction II, then after the given time fraction III and then the next day, fraction IV.

Table 4 shows that it takes 2 hours and 25 minutes to draw all the fractions for ten analyses. The operation cannot be performed in a shorter time. During the time interval between the drawing of fraction III and IV, samples are prepared for the next analyses. In addition, one analyst may work on two apparatus simultaneously; then he begins work on one apparatus at 9 a.m. and on the other at 11 a.m. the same day. The prepared samples must already be placed in the cylinders when he begins his work on each apparatus.

In the same manner working tables are prepared beforehand for various temperatures and the required temperature is selected from these. Working tables are prepared the same way for samples of a different specific gravity, if it is necessary.

In order to evaluate the reproducibility of analyses with the proposed apparatus, comparisons were made with the apparatus and by the pipette method. N. I. Volotovskaya analyzed a sample from the plowed layer of sod-podzolic, fine clay loam ten times in the soil science laboratory of Chernovitsy University (3). The results obtained are given in Table 5. As may be seen from the table there is a good agreement between the average values for various separates. In addition, the deviations between extreme values are considerably smaller for the apparatus of our design than for the usual pipette

APPARATUS FOR MASS PARTICLE-SIZE ANALYSIS

hod. This is certainly due to the more objective conditions of analysis in the proposed apparatus.

A good agreement was also found in comparisons made by L. A. Sinyavskaya and S. S. Mik in the laboratory of the Ukrainian Agricultural Scientific-Research Institute (G. N. Chur laboratory), where coarse-textured soils were primarily analyzed. The results are given in Table 6. The deviations are within the limits of accuracy of particle-size analysis.

It must be noted that when the time is planned properly, analysis with the proposed device is much more rapid than with any other pipette method (4), and the accuracy of the results is lowered. One analyst can make more than 120 analyses per month with one device and more than 120 with two.

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PROBLEM OF THE INFLUENCE OF MOISTURE ON THE BULK DENSITY OF SOILS

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The determination of the hydrophysical properties of soils has acquired a great practical importance in relation to the expansion of irrigated areas and the development of meliorative and agricultural practices for the increase of the fertility of irrigated lands. One of the principal indices of the hydrophysical properties of soils is their bulk density, which characterizes the structural compactness of the soil as a whole and of its individual horizons.

The physical properties of soils, especially of clay and fine clay loam solonetz-like soils, are characterized by a certain dynamism and very depending on the degree of moistening. Soils which are saturated with moisture are more homogeneous in structure, while desiccation often leads to cracking and the formation of lumps. Cracks reach a width of 3-5 cm and a depth of 80-100 cm and sometimes even more; the diameter of the lumps varies from 5-10 cm to 20-30 cm and more. The solonetz-like soils of the Kura-Araks lowland and especially those of the eastern part of the Shirvan Steppe are very fissured.

Modern methods of determining the bulk density of soil do not take into account the cloddiness and fissuring of soil, since bulk density is determined from small samples, 20-30 cm³ or 100-200 cm³ in volume, which are generally taken from the center of clods which are most homogeneous in structure. Consequently, the bulk density of the soil relates only to clods and not to the entire soil, so that all calculations containing bulk density change correspondingly.

In addition, the bulk density of soil is usually determined under field conditions during various seasons and under varying soil moisture conditions, and consequently under differing conditions of shrinkage, fissuring, and cloddiness. As a result, bulk density differs even for one and the same soils and is highest for dry soils and least for soils saturated with moisture. The change in bulk density under various moisture conditions does not permit one to compare soils and their individual horizons as far as their density is concerned.

The field moisture capacity of cloddy and fissured solonetz-like soils, as reduced to volumetric values by using bulk density determined in dry soils, is usually 5%-10% and

sometimes 15%-20% higher than porosity. This is explained by the fact that soils swell when saturated with water so that their bulk density is decreased and their porosity increased.

Proceeding from the structural variations of solonetz-like soils in the Kura-Araks lowland, dependent on the degree of moisture, the bulk density of soil has been determined in the last ten years in the soil-melioration sector of the Azerbaydzhan State Institute for the Planning of the Water Economy both under natural moisture and under field moisture capacity, i.e. the saturation of the soil to the ultimate moisture capacity after all gravity water has drained. The density determined under field moisture capacity is used in calculations.

Soil which is moistened to field capacity has the most homogeneous structure, the clods are swollen and occupy the largest volume, fill cracks in the soil, and the loosened plowed zones compact when gravity water drains.

The first comparisons of the bulk density of desiccated soils under field moisture capacity were determined by the author in 1949 in the Lenkoran lowlands and in the Apsheron Peninsula. Additional material was obtained in 1952-1953 for the Shirvan Steppe, which serves as a basis for the present communication.

Field determinations of bulk density were made in autumn; at this time the soils were desiccated and the fissures and lumps were pronounced. Kachinskiy's sampler, of a capacity of 200 cm³, was used in the bulk density studies. This sampler was driven into the soil according to a metal guide with a hydraulic automobility. The upper end of which was propped against the front fender of a car. The bulk density of dry and moist soils was determined at 16 points to a depth of 1-2 m, repeating the measurements three for each 10-cm layer in the first meter and each 20-cm layer in the second meter. The results of bulk density determinations in each horizon under natural soil moisture and under field moisture capacity are given in Table 1. The table gives variations in bulk density at the most characteristic points and only in the upper 0-1 m, where it is subjected to the greatest variations.

Bulk density determined at field moisture capacity is least in the upper layer and increases

MOISTURE INFLUENCE ON BULK DENSITY

Table 1
Bulk density under various moisture conditions

Depth, cm	Point								Average				Porosity, taking into account bulk density at:	
	28		35		40		43							
	natural moisture	field moisture capacity	natural moisture	field moisture capacity	natural moisture	field moisture capacity	natural moisture	field moisture capacity	natural moisture	field moisture capacity	natural moisture	field moisture capacity	natural moisture	field moisture capacity
0—10	1,60	1,31	1,54	1,28	1,58	1,40	1,56	1,30	1,570	1,322	41,9	51,1		
10—20	1,75	1,39	1,51	1,21	1,53	1,45	1,59	1,31	1,595	1,340	40,8	50,4		
20—30	1,63	1,38	1,50	1,29	1,62	1,45	1,59	1,40	1,585	1,380	41,2	49,7		
30—40	1,53	1,35	1,51	1,45	1,73	1,50	1,67	1,40	1,610	1,425	40,4	46,1		
40—50	1,53	1,35	1,60	1,55	1,73	1,52	1,59	1,40	1,610	1,455	40,4	46,1		
50—60	1,55	1,36	1,59	1,46	1,65	1,55	1,55	1,44	1,585	1,452	41,2	46,3		
60—70	1,50	1,46	1,58	1,46	1,63	1,55	1,56	1,50	1,567	1,492	42,2	45,2		
70—80	1,49	1,49	1,45	1,40	1,61	1,61	1,52	1,50	1,517	1,500	43,0	44,4		
80—90	1,53	1,50	1,53	1,44	1,63	1,60	1,51	1,54	1,550	1,502	42,7	44,1		
90—100	1,59	1,55	1,57	1,51	1,63	1,58	1,53	1,52	1,580	1,540	41,5	43,0		

Note: Comma represents decimal point.

with depth (Table 1), which is fully consistent with the structural profile. In this manner we find its average value, which characterizes the structure and compactness of the soil.

Soil porosity, calculated by taking into account the bulk density of dry soils, is too low, since it characterizes the porosity of clods only and not the porosity of the whole soil which contains a great number of cracks which are avoided when selecting the place for sampling. As a result, porosity variations in the upper 1 m reach on the average 5%-6% of the volume, which is 500-600 m³/ha. These variations in porosity are substantial when calculating irrigation rates, determining the amount of salts and nutrients, water losses, etc.

Conclusions

1. Comparison of bulk density at natural moisture and at field moisture capacity showed that the bulk density of clay solonetz-like soils of the Kura-Araks lowland is not a constant value; as soils become more moist and swell, their bulk density decreases, while when they become dry and shrink, it increases.
2. The highest changes of the bulk density of soils in a dry state at field moisture capacity occur in strongly solonetzic swelling clay soils of the Shirvan and Karayaz Steppes.

The bulk density in non-solonetzic structural soils does practically not change with moistening.

3. Bulk density is most accurately determined under similar moisture conditions, namely: under the field moisture capacity of soil.

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SIMPLE ATTACHMENT TO THE FEK-M PHOTOELECTRIC COLORIMETER FOR EMPTYING CELLS

S. T. LIGUM, Experimental Breeding Station of L'gov

When emptying the liquid from the cell of the FEK-M colorimeter, the optical surface is often dirtied by the liquid. This requires the additional cleaning of the cell. When cells are often removed from the holder for cleaning, care must be taken to place them in the proper position in their corresponding places in the holder and this requires additional time and the attention of the analyst, and reduces the work output.

As reported by P. A. Baranov and N. P. Karpinskiy,¹ special cells are used with photoelectric colorimeters in the German Democratic Republic, which permit one to empty the cells without taking them out of the holder. An electromagnetic device is used for this with which it is possible to lift the stopper of the drain hole of the cell and drain the liquid and then close the hole without touching the cell with the hands. Such a method as used in the German Democratic Republic requires a modification of the cells.

In our laboratory we used a simple attachment to the FEK-M colorimeter which allows us to empty the cells without removing them from the holder and without changing their construction.

The attachment consists of the use of the vacuum created by the water pump used for siphoning the liquid from the cells.

One end of a thick-walled rubber tube with an outside diameter of 7 mm and an inside diameter of 4 mm is connected to the water pump. The other end of the rubber tube is fitted with a thick-walled end piece of glass 7 cm long, having an outside diameter of 6 mm, and an inside diameter of 1.5 mm. The end piece tapers at the outlet end where it has an outside diameter of 3 mm and an inside diameter of 1.2 mm. Such end pieces are made by us of thick-walled graduated pipettes of 2 ml capacity.

An iron stand with clamps 45 cm high is placed next to the colorimeter near the right cells. The rubber tube is passed through the clamp in such a manner that the end piece can easily reach the bottom of the right cell. By pulling on the tube, which moves freely in the clamp, one may reach the bottom of the left tray with the end piece, if necessary. The water pump is turned on. The end piece is immersed in the cell and the solution is siphoned out. The speed of siphoning depends on the size of the cell, the magnitude of the vacuum, and the diameter of the opening in the end piece. All this can be regulated. Using a glass end piece with an outlet opening of 1.2 mm, the water faucet is opened full strength. After the analyzed solution is drawn out, the next test solution is poured into the cell to clean it, the end piece is immersed in the cell and the solution is siphoned out again. If a drop of solution should be left in a corner of the cell, it is siphoned out by placing the end piece over it. When the liquid is completely removed from the cell, the end piece is released from the hands and hangs freely on the elastic rubber tube on the right side of the cell, from which it is conveniently picked up for the next siphoning.

The water pump is not turned off during work. The cells are filled with the test solution from 100- and 50-ml volumetric flasks without removing them from the holder. Cells 50 mm, 30 mm, 20 mm, and 10 mm long may be used. The filling of these cells with the liquid requires a certain experience. The neck of the flask is held over the longest side of the cell, i. e., lengthwise for cells 50 mm and 30 mm long, diagonally for the 20 mm cell, and across for the 10 mm cell.

The use of the foregoing device greatly facilitates the work of the analyst and increases his output by not less than 50%.

¹Use of fertilizers in the German Democratic Republic, 1957. Sel'khozgiz.

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COMPILATION OF A BIBLIOGRAPHY ON THE SOILS OF THE USSR ACCORDING TO ZONES

A. E. RABIN

In order to utilize and increase fully soil productivity a comprehensive knowledge of soil and climatic conditions by zones, regions, and individual farms is required. The search for and selection of needed material among the rich literature on soil science are associated with great difficulties. A bibliography is needed to help agricultural specialists, scientists, teachers, and university students. A current bibliography has been published in the journal "Soil Science" for nearly 60 years. Corresponding sections may also be found in the subject index "Agricultural literature of the USSR" (published since 1948) and the abstracting journal "Biology" (published since 1954). Such known sources of the universal bibliography as "Book Chronicles" and "Chronicles of Journal Articles"¹ may serve for the same purpose. Sometimes information is required on the literature of many years. A compound bibliography is needed which would cover the literature dating a long time back.

However, the literature is not arranged by zones in the existing bibliographies on soils science. In order to find the material referring to soils of individual areas one must not only search current bibliographies, but also descriptions in works on soil science. There are either no auxiliary indexes, in particular regional ones, or they only begin to appear. The subject index to the abstracting journal "Biology," which contains regional sub-headings under the heading "Soils," was compiled for the first time in 1958. The quarterly subject index to the "Book Chronicles" may be used for this purpose, but it also began to appear since the third quarter of 1956.

Literature lists at the end of books or articles on soils, partly on the geography and economy of individual areas, may serve as sources for a soil science bibliography arranged by zones; but their use is very difficult. These lists^{*} are usually included in the general author and name index.

A bibliographic index, "Soils of Southeastern European USSR," has been issued by the Scien-

tific library of Saratov University in 1959.² It was compiled on the basis of an extensive card file, the bibliography in the journal "Pochvovedeniye," the "Chronicles" of the All-Union Book Chamber, and other bibliographic sources. The volumes of scientific journals, such as the "Transactions" and other collections were also searched, going many years back. The bibliography includes more than 2000 references to works published until 1956, including those which even partly refer to the soils of the Southeast. The material is arranged in 18 sections, some of which ("Soil formation. Geography of soils., " "Soil melioration," etc.) have subdivisions. Short annotations are given if necessary, which primarily specify the place and nature of the investigations. An author and geographical index are included, from which the material referring to a geo-geographic or administrative region, an individual farm, and a plot can rapidly be found.

The index to the literature on the soils of the Southeast is undoubtedly of a great practical value. Such indexes must be compiled for the soils of all zones in accordance with the newest natural and soil-geographic regionalization.

The compilation of fundamental bibliographies is within the power of the largest libraries, such as those of the departments and branches of the Academy of Sciences of the USSR, of academies of sciences of the republics, of universities, and of certain republic, provincial, and regional libraries. Duplication must be avoided and it is very important that all cooperate in the compilation of fundamental bibliographic reference works within each zone. Certain libraries have already begun to compile such bibliographies. The Eastern branch of the library of the Academy of Sciences of the USSR (Novosibirsk) has planned the publication of a series of reference works in the form of the "Bibliography of natural conditions and natural resources of Western Siberia." The compilation of a bibliography on the soils of the USSR according to zones must be included in the com-

¹For an example we may refer to the old bibliographic index: P. V. Ototskiy. 1898. Literature on Russian soil science from 1765-1896. St. Petersburg. 153 pp.

²Bychkova, Ye. Kh. and Yu. O. Biblio. 1959. Soils of Southeastern European USSR. Bibliographic index. Edited by A. P. Malyanov. Saratov. 253 pp. (Nauchn. b-ka Sarat. gos. un-ta im. N. G. Chernyshevskogo. Bibliografiya. Sarat. obl. No. 4).

COMPILATION OF A SOIL BIBLIOGRAPHY

ite plan for bibliographic work, developed
the Council on the problems of library
rk under the Ministry of Culture of the USSR.
seems that the role of the coordinating center

on soil bibliographies should be played by the
library of the Soil Institute of the Academy of
Sciences of the USSR.

REPLY TO N. N. BOLYSHEV

A. A. RODE

Number four of the journal "Pochvovedeniye" for 1960 contains an article by N. N. Bolyshev (1) in which he presents my views on certain problems of soil formation in a distorted way. Reserving for myself the privilege of commenting on the ideas of N. N. Bolyshev as a whole in another place and at another time, I will reply to him in the present note with reference to the distortion of my views.

The principle "charge" of N. N. Bolyshev against me consists in that "... Rode objectively used the existing contrasting phenomena and processes to substantiate his old position, that is, the climax of soils." Bolyshev tries to substantiate his charge by the following statements: "Judging by the reading of the arrows, these contrasting processes take place with equal force and rate, even though they indicate the presence of movement, but the latter is only a temporary deviation now to one side and now to the other, indicating a state of constant equilibrium."

Let us explain that in speaking of arrows and contrasting processes Bolyshev has in mind those important contrasting processes which, in my opinion, are the basis for the soil-formation process. The scheme with the arrows is described by me in my textbook "Soil Science" (3, p. 291-292).

The arrows in my scheme are actually of the same length, being oriented in various directions. In working out this scheme I did not think that the equal length of the arrows would make others suspect that I am an advocate of such views as "mobile equilibrium," or of the "theory of the climax of soils." The only purpose of these arrows was to show the existence of opposing processes in the soil relating to one and the same groups of material, or forms of energy. If N. N. Bolyshev would have taken the pain of reading my textbook more carefully, he would have found that after having discussed the nature of the contrasting phenomena constituting soil formation, I explain on page 292 that "Phenomena constituting the process of soil formation, take place simultaneously and interact with each other. These

phenomena take place at varying rates in the various soil layers; one and the same phenomenon may take place in one soil layer and be absent in another..." And further: "Elementary phenomena, constituting the process of soil formation, behave differently, depending on the conditions under which they occur." Further, I explain that these conditions influence the existence, direction, and rate of individual phenomena from which the process of soil formation is composed, and, consequently, the speed, direction and the degree of development of this process itself. Where is "mobile equilibrium" here?

I suppose that what I have said is sufficient to relieve me of the suspicion that by means of the arrows of equal length I meant to stress the idea of the climax of soils in mobile equilibrium.

I must remind N. N. Bolyshev here that I previously analyzed the concept of "climax" from the point of view of soil science in one of my earlier articles in 1947 (2), and based on actual material, showed the incompetence of this idea. As far as I know no other soil scientists, except me, has subjected the climax theory to criticism. It is difficult to believe that Bolyshev was not familiar with this book and that more strange his accusations seem.

A number of smaller criticisms directed against me by Bolyshev are based on an obvious misunderstanding of what I have said, and I will not insist on them.

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THE SECOND INTER-UNIVERSITY CONFERENCE ON THE PROBLEM OF MICROELEMENTS AND THE NATURAL RADIOACTIVITY OF SOILS

A. ALEKSAKHIN and V. D. VASIL'YEVSKAYA

The Second Inter-university Conference on the problem of microelements and the natural radioactivity of soils in the USSR took place on March 16-19, 1960, at the Biological-Soil Faculty of Moscow State University. It discussed the results of work conducted since the last Conference was held.

Eighty-eight lectures, presented by universities, agricultural institutes, and other scientific-research institutions, were read and discussed at plenary meetings and at the sessions of four working groups (soil science, plant physiology and agrochemistry, natural radioactivity of soils, and methods of determining microelements in soils and plants).

In his lecture on "Microelements and the natural radioactivity of soils in the Ukrainian SSR," Academician P. A. Vlasyuk (Kiev) of the Russian Lenin Agricultural Academy, discussed the results of long-term studies of the content and the content of available microelements of the most important microelements in the soils of the Ukrainian SSR, and the determination of the effectiveness of the use of microelements in fertilizers (manganese superphosphate and nitrophoska, boron superphosphate, and others). Studies on the natural radioactivity of soils in the Ukrainian SSR revealed certain principles in the distribution of the β -activity of soils, depending on their genesis and degree of fertility.

Biogeochemical prospecting takes on more and more importance in the search for ore deposits. The lecture of M. A. Glazovskaya (Moscow State University) was devoted to the development of the principles of this method. She demonstrated certain principles in the distribution of microelements in soils, plants, and water in relation to the search for copper ore, taking the Southern Urals as an example.

E. P. Troitskiy (Moscow State University) discussed problems of the influence of microelements on biological processes. In living organisms microelements play the role of strong activators of biochemical and physiological processes. They form part of compounds for organisms (hormones, ferments, and vitamins).

V. Akimtsev discussed the preliminary

results of work conducted at Rostov University on the problem of microelements. On the basis of studies of the content of microelements in the soils of the Lower Don and Northern Caucasus, the suggestion was made to make this area a separate biogeochemical province.

The main topic of lectures in the soil science section (Professor V. V. Akimtsev, chairman) was the problem of mapping soils in individual regions according to physiologically important microelements (B, Mn, Co, Zn, Cu, Mo, J, etc.). Investigations were made on the content of microelements in soils of formerly unexplored regions (by M. A. Toykka in the Karelian ASSR, by M. I. Orlova in the Mordvinian ASSR, by V. P. Kamchatnov in the Mari and Tatar ASSR, by V. D. Rudin in Stavropol' Province, by V. D. Kucherenko in the Orenburg Region, and by O. V. Makeyev and others in the south of Central Siberia). The continuously increasing volume of work in this field makes the solution of such a problem as the compilation of a map on the distribution of microelements in the soils of the USSR more imminent.

Lectures were given on the interaction between a number of diseases (endemic goiter, cancer, etc.) and the presence of certain microelements in the soil (by Yu. G. Antonov of the Academy of Medical Sciences of the USSR, A. S. Ivanov and A. N. Tyuryukanov of Moscow State University, and V. V. Akimtsev and P. A. Sadimenko of Rostov University). The establishment of this relationship may lead to the right road to the elimination of these serious diseases.

The work of the section on plant physiology and agrochemistry (Docent V. D. Rudin, chairman) was concerned with a number of problems related to the study of the effectiveness of microelement fertilizers and the treatment of seeds with microelements before sowing, as well as the study of the effect of microelements on fermentation, the oxidation-reduction, photosynthesis, respiration, carbohydrate exchange, the water regime of plants, etc. The undoubtedly positive effect of micro-element fertilizers on the yield of agricultural crops was mentioned in the lectures and it was pointed out that not enough fertilizers, such as manganized and molybdenized superphosphates, boron superphosphate, etc., are used in kolkhozes and sovkhoses. It was found desirable to expand the investigations of little studied microelements (Ti, Ni, Cr, V,

Sr, Ba, J, Br, As, etc.).

The results of investigations on the content and behavior of radioactive elements in soils were reported in the section on the natural radioactivity of soils (Professor V. I. Baranov, chairman). M. T. Yastrebov (Moscow State University) gave a lecture on "The natural radioactivity of certain zonal soils of the USSR", and A. A. Titlyanova (Urals Branch of the Academy of Sciences of the USSR), A. N. Tyuryukanov, and others (Moscow State University) discussed the characteristics of the behavior of the radioactive isotopes strontium and cesium (Sr^{90} and Cs^{137}) in soils. R. M. Aleksakhin (Moscow State University) gave a review of the global pollution of the biosphere by radioactive substances.

A number of lectures were given in the section on methods of determining microelements (N. G. Zyrin, chairman).

V. I. Kuznetsov (Geochemical Institute of the Academy of Sciences of the USSR) gave a lecture on the determination of microelements by means of organic co-precipitants. The high selectivity and great selection of precipitants are an additional advantage of this method of analysis.

Interesting lectures were given on the use of the following methods for the determination of the content of microelements in soils and plants: spectral analysis, by N. G. Zyrin and G. D. Belitsyna (Moscow State University); neutron activation analysis, by A. A. Sobachkin, V. B. Mogilevkin, and B. S. Prister (Timiryazev Agricultural Academy); polarographic methods, by D. S. Orlov (Moscow State University), A. A. Sobachkin, and B. S. Trister (Timiryazev Agricultural Academy);

cation exchange resins, by Ye. V. Arinyshkin, and M. Ya. Volkova (Moscow State University); and complex-forming reagents, by L. K. Ostrinskaya and others (Physiological Institute of the Academy of Sciences of the Ukrainian SSR).

The conference showed that the institutions higher learning in the country conduct extensive investigations on the problem of microelements and the natural radioactivity of soils. The importance of experimental work confirming the effectiveness of many microelements in increasing the yield of agricultural crops has been expressly noted.

The resolution of the conference on the future tasks in the study of this problem includes: the compilation of maps on the content and forms of microelement compounds in the major soil groups, soil-forming parent materials, and vegetation of the Soviet Union, and maps of the requirements and effectiveness of microelement fertilizers in various zones, detailed investigation of the exchange of microelements in the system: parent material — soil — ground water — plant, and the expansion of studies on the effectiveness of the use of microelements in the form of fertilizers. One of the most important tasks in the field of soil radiology is the compilation of a map on the distribution of natural radioactive elements in the soils of the USSR. A number of concrete recommendations on the method of determining microelements was worked out at the conference.

The next, III, Inter-University Conference on the problem of microelements and the natural radioactivity of soils is to be held in the second half of 1961 at Rostov on the Don.

PETER VASIL'YEVICH VERSHININ

Members of the Agrophysical Institute

Professor P. V. Vershinin, a great scientist in the field of soil physics, died on January 5, 1960, after a short, severe illness. The members of the Agrophysical Institute and Soviet agrophysics lost in him one of the founders of agronomical physics.

P. V. Vershinin was born in 1899 to a family of farmers in the village of Sorokino, Rybnik district, Ryazan' Government. Peter Vasil'yevich graduated from the municipal lyceum at Yaroslavl' in 1914 and from the Rybnik geodetic college in 1918, after which he worked as a geodesist in Yaroslavl'. Peter Vasil'yevich joined Yaroslavl' University and in 1924 graduated from its agronomical faculty. In 1930 he worked with land organizations in Yaroslavl'. In 1930 he enlisted, at the request of civic organizations, as a graduate student at the All-Union Lenin Agricultural Academy, and after finishing it, defended his dissertation "Agricultural characterization of the soils of Pskov district." From then on Peter Vasil'yevich worked permanently at the Agrophysical Institute. He left the scientific laboratory only during World War II to defend our country. He received several medals during the war.

The scientific activity of Peter Vasil'yevich was essentially devoted to one problem—soil structure. P. V. Vershinin was a true innovator in this field. In the early years of his work at the Institute he established, together with the physicist, V. P. Konstantinova, the physicochemical principles of the development of soil structure and wrote a monograph which was published in 1935. Many pages of this monograph have retained their importance to this day.

Further investigations by means of the new physical methods lead P. V. Vershinin to create a unified, strictly logical theory on the development of soil structure and the formation of fertility in it. He established two stages of development of soil structure: 1) the formation of the microstructure as a result of the co-

agulation of soil suspensions and the sticking together of particles; and 2) the appearance of the macrostructure as a result of the cementation of microaggregates, or primary particles, by humic materials. He proved by direct experimentation that water-stability is impossible without humic materials. He also demonstrated on the basis of extensive geographical material the total dependence of water-stability on the humus content in soil, and especially on the content of humic materials. As a result of the analysis of processes of structure formation and the mechanism of the development of water stability, he was able to advance the idea of synthetic structure formation and substantiate certain technical aspects of methods for activating structure formation as early as in the early 1930's.

Peter Vasil'yevich generalized his main investigations on the structure of soil in a large monograph, which he successfully defended as his dissertation for a doctor's degree in agricultural sciences in 1956.

He devoted the rest of his life to investigations on the restoration of soil structure by means of polymerizing materials.

Peter Vasil'yevich Vershinin constructed a number of unusual instruments. His method and instrument for determining the water-stability of soil are very interesting and are widely used in detailed investigations. He is the author of 50 original published works, among which three monographs which are widely known both in our country and abroad. Many students of Professor Vershinin are now great scientists and continue the investigations of their teacher.

Soviet soil science and agricultural physics lost a great scientist and social worker in Peter Vasil'yevich Vershinin and a comrade devoted to the end to communism. His memory will be with us to our last day.

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